Product differentiation, collusion and standardization

Han, X.

Publication date:
1998

Document Version
Publisher's PDF, also known as Version of record

CentER
for
Economic Research

Product Differentiation, Collusion, and Standardization

Xiangzhu Han

Tilburg University

Product Differentiation, Collusion, and Standardization

Product Differentiation, Collusion, and Standardization

PROEFSCHRIFT

ter verkrijging van de graad van doctor aan de Katholieke Universiteit Brabant, op gezag van de rector magnificus, prof. dr. L.F.W. de Klerk, in het openbaar te verdedigen ten overstaan van een door het college van decanen aangewezen commissie in de aula van de Universiteit op

vrijdag 16 januari 1998 om 16.15 uur

door

Xiangzhu Han

geboren op 20 oktober 1963 te Shandong Province, P.R. China

PROMOTOR: Prof. dr. P.H.M. Ruys

To my parents

Acknowledgements

This thesis is the result of four years of research carried out at the Department of Econometrics and the CentER for Economic Research of Tilburg University. I would not have accomplished this thesis without the help of many people in the various phases of the research. I would like to make use of this opportunity to acknowledge their contributions, realising that such a list can never be complete.

I am greatly indebted to Professor Pieter Ruys for providing excellent supervision. His kindness, care, and encouragement gave me this opportunity, so that my dream to understand the firm's behaviour comes true. He stimulated my interest in the fascinating topic as developed in this research by making numerous comments and remarks, aimed at this research as well as at my further development. I would also like to thank the other members of my thesis committee, Professor Eric van Damme, Dr. Dave Furth, Professor Dolf Talman, Professor Gerard van der Laan and Professor Jean Jaskold-Gabszewicz for their interest in my work.

I acknowledge Professor Patrick Bolton, Dr. Yossi Spiegel, and Professor Nicolas Schmitt for their constructive comments. I am grateful to Professor Dolf Talman for his tremendous support. He was always willing to read the initial draft of the research, and to give quick, yet critical comments.

I gratefully appreciate my colleagues' support. I owe special thanks to Chris van Raalte, Antoon van den Elzen, René van den Brink, Harry Webers, Maria del Pilar Montero, Vincent Verouden, Zaifu Yang, and Haoran Pan for discussing my papers with me and providing a pleasant atmosphere.

I would like to thank the Department of Econometrics for providing excellent research conditions and the CentER for Economic Research and NAKE for creating a stimulating research environment and inviting many interesting guests.

I am glad to acknowledge the excellent assistance provided by the secretaries at the Department of Econometrics and the CentER for Economic Research. I would like to thank, in particular, Jeanine Leytens-van Strien and Inez Hoondert for their great help of making my life easier at the very beginning of my staying in Tilburg, as well as Petra Ligtenberg and Cun Tuerlings for being always kind and helpful.

Last, but not the least, I would like to express my thanks to my parents, relatives and friends for their support. I am particularly grateful to my wife Sun Yanli for her encouragement and her tender love and care.

Tilburg, November 1997

Contents

Chapter 1

Introduction

This monograph has its roots in theoretical product differentiation, with its extension to deal with collusion and standardization problems encountered in industrial organization. Product differentiation, collusion and standardization are among a firm's main business strategies in an oligopoly. Each strategy influences - and is influenced by - the other strategies and the firm aims to maximize its profit through these strategies. This monograph develops these three concepts and their implications.

1.1 Concepts

1.1.1 Product differentiation

Firms differentiate their products in one way or another, but mainly in four ways.[1] First, they select plant or store locations more convenient (in terms of travel time and/or transportation costs) than rival locations. The locational advantages of the corner drug store and the local gravel quarry are illustrations. Second, they offer exceptionally good (or bad) service. Some retailers maintain large and well-trained staffs to provide prompt, intelligent, and courteous service; others are better known for long check-out lines and grumbling cashiers, mollifying the effect with rock-bottom prices. Some computer manufacturers contribute an array of free programming services to those who use their machines; others offer no application programming; and so on. Third, there are physical differences in the products supplied. A suit may incooperate the most finely woven wool worsted or a coarser substitute; an automobile may navigate curves surefootedly or clumsily; a television receiver may project vivid or muddy colour; and so forth. Finally, products are differentiated in terms of subjective image they impress on consumers. Firms at-

[1] See Scherer (1980), p.375.

tempt to enhance the image of their products through brand labelling, advertising, direct word-of-mouth sales promotion, and the design of attractive packages.

Much, perhaps most, product differentiation effort observed in a modern private enterprise economy represents a natural and healthy response to legitimate demands; people's wants are diverse, and consumers plainly desire a varied menu of consumption opportunities. It is a rare consumer who does not value convenience in the location of suppliers, and many will pay a price premium for a certain amount of locational convenience. Almost every consumer prefers good service over poor, though the prices individuals are willing to pay for extra service vary widely. The diversity of preferences with respect to physical design and performance characteristics is especially great. Some men prefer cotton shirts, some silk shirts, some hair shirts, and some no shirt at all. Likewise, different consumers place varying weights on the subjective image accompanying the products they buy.

The main feature of product differentiation from the point of view of both the supply and the demand can be captured by distinguishing between *horizontal* and *vertical* differentiation. Two variants of a product are said to be horizontally differentiated whenever, if sold at the same price, one variant is chosen by some consumers, while the alternative variant is chosen by others. Two variants are vertically differentiated whenever, if sold at the same price, the same variant is purchased by all consumers - although the prices consumers are willing to pay for a variant may vary (such is the case of a "standard" and a "luxury" product).

The economics of product differentiation studies how much product differentiation there should be from the point of view of both firms and the social planner, and whether certain market conditions might lead to excessive or inadequate differentiation, or to the "wrong" kinds of differentiation.

1.1.2 Collusion

If oligopolists make an agreement as a result of repeated price interaction in a purely non-cooperative manner, we have *(tacit) collusion.* With repeated interaction, a firm must take into account not only the possible increase in its current profit, but also the possibility of a price war, or retaliation, and the long-run losses when deciding on whether to undercut a given price. As Chamberlin (1933, p.48.) conjectured, if each oligopolist seeks his maximum profit "rationally" and "intelligently", he will realize that when there are only two or a few sellers, his own move has a considerable effect upon his competitors, and that this makes it idle to suppose that they will accept without retaliating the losses he forces upon them. Since the result of a cut of the given price by any one is inevitably to decrease his own profits, no one will cut, and although the sellers are entirely independent, the equilibrium result is the same as though there were a monopolistic agreement between them.

The framework of a supergame provides a technically easier approach to study (tacit) collusion. The supergame is a price game repeatedly played for finite or infinite times. For a certain future discount value and well defined strategies, oligopolists may reach collusion as an equilibrium if the price game is repeatedly played for an infinite number of stages. This collusive behaviour of oligopolists may significantly influence – and be influenced by – their degree of product differentiation, which provides policy implications for welfare analysis or optimal product selection.

1.1.3 Standardization

Standardization, or compatibility, is a technological adoption of the common industry standards. Product differentiation is not always a good thing; apart from the cost savings attainable through longer product runs, there are cases in which standardization serves consumers better than diversity. The adoption of common technical standards for records and compact discs, so that any product can be played on any manufacturer's audio equipment, is an example. Similarly, typewriter keyboards are standardized on the QWERTY system so that users can move easily from one machine to another, even though appropriately trained persons could type much faster on alternative keyboard layouts. The use of computers would be facilitated in numerous applications if compatible data coding conventions and programming languages were adopted.

Convergence toward a common industry standard may be difficult, however, when early adopters incur costs or lose sales to rivals, as a result of pioneering. Once they are established, standards may persist beyond their useful life because the first firms to change encounter resistance from already committed users, and are unable to capture the benefits accruing to the customers of rivals who might follow suit. Recognizing the difficulties of standard changing, industry members often form cooperative standard committees to coordinate on product specifications and interfaces. These may have negative and positive effects; for example, they may serve as a forum for collusion, or insiders may influence the standards adopted so as to make entry more difficult for outsiders. Even without such formal coordination, entrenched incumbents may, by preempting the announcement of new standards or taking predatory actions inhibiting the growth of smaller rivals, prevent the emergence of standards that would prove to be superior if they could gain a sufficient foothold. Little is known about the distribution of benefits and costs from such standard-setting activities under different market structures.

The economics of standardization is studied mainly with two approaches: the *network* *externalities* and the *mix-and-match* approach. In the presence of network externalities, the valuation of a good increases with the size of the standardized, or compatible, network. This network may consist of a number of consumers who use compatible technologies and/or of a number and variety of compatible complementary products. We may distinguish between *direct* and *indirect* network effects. Direct network effects arise when users benefit from being linked, physically or psychologically, to a large number of other agents. This may happen, as in the case of phone or e-mail networks, because consumers want to be able to communicate with a large group. Alternatively, as illustrated by the importance of fashion, consumers might just derive some satisfaction from buying the same product as others. On the other hand, indirect network benefits come from improvements in the supply of complementary inputs. An increase in the sales of a given product may result in lower prices, better quality and/or greater variety for other goods or services required for the good to be useful. Greater sales of Philips' DCC machines are likely to lead to a greater variety of titles available in DCC format. Similarly, the popularity of WordPerfect makes it easier for an office manager to find help from those who use that word processor.

In the "mix-and-match" approach, consumers are interested only in using systems made of several horizontally or vertically differentiated components. Interbrand compatibility may then increase industry demand by allowing consumers to assemble systems that are closer to their ideal specifications. As examples, one may think of audio systems made of loudspeakers, receivers, CD players, and tape decks, or of video systems which include a TV set, a VCR, and a video camera. The effects emphasized by the mix-and-match approach are rather different from those identified by the network externality approach. These two approaches differ in the type of compatibility linkages they address, in the assumed relationships between compatibility, variety and product differentiation, and, therefore, in the mechanisms through which standardization affects prices, profits and welfare.

1.2 The scope and method of the research

The interests of this monograph are twofold. First, product differentiation theory is pursued to explain the prevalence of differentiated goods in a market economy. The basic models are enriched by adding several elements – competition from outside goods, competition and cooperation, and non-uniform but concentrated consumer distributions. New insights are obtained. Then, product differentiation theory is applied to particular markets, such as durable goods markets, to study the business strategies of firms and their economic implications. The focus of the application is the *economics of standardization* and its implications for *antitrust* and *international trade policy* issues.

Differentiated markets are observed rather often; important economic properties can be explained properly by product differentiation models. Two basic models emerge corresponding to the horizontal and vertical differentiation, respectively: The *location* or *spatial differentiation* model, and the *vertical differentiation* model. In this monograph, we are interested in competition between a small group of competitors – oligopolists – and hence we focus on duopolists. For these interests, we shall employ a game-theoretic approach to study and develop these basic models. We take as given the nature of consumers' tastes, the specification of technology, and a suitable notion of what would constitute an equilibrium in the particular problem under consideration.

The models used to study the problems employ the game-theoretic equilibrium and use comparative statics to derive implications. Firms are assumed to choose among those alternatives that maximize profits, while consumers are assumed to choose among those alternatives that maximize their utilities.

A complete model of product differentiation incorporates, first, the set of possible products, second, the technology used for each product, third, the tastes of consumers over the set of possible products, and, fourth, an equilibrium concept. At any significant level of generality such a model seems intractable. Hence, certain simplifying assumptions must be made.

Applications will be developed by means of the mix-and-match approach. With this approach, product differentiation models provide suitable tools for formulating and analysing many important aspects of the economics of standardization: standardization choices, related policies, and some antitrust implications and international trade policies.

1.3 Product differentiation and standardization models: A survey

1.3.1 History

A brief outline of some of the key points in the historical development of models of product differentiation may help to put the material discussed in this monograph into perspective. Also, the history of the economics of standardization is reviewed briefly at the end of this section; there we are interested mainly in standardization and its implications for antitrust and international trade policies. Because of space limitations and the extensive literature, we mention only the main contributions. Our concern is with the flow of ideas, and we mention names only as illustrative benchmarks.

The history of product differentiation models

Shortly after the death of Alfred Marshall, Sraffa (1926) pointed out the inconsistency between the observed facts of unexploited scale economics in many manufacturing industries and the Marshallian theory of perfect competition, where all scale economies must be exhausted in the long-run equilibrium.

Chamberlin (1933) responded to Sraffa's challenge. In his theory, a large group of competitive firms, each producing one differentiated product and operating under conditions of free entry, produce in equilibrium outputs less than the minimum efficient scale. This theory was a triumph in making a small amendment – differentiated products – to Marshall's theory of perfect competition, which then reconciled competitive theory with the empirical observation of unexploited economies of scale.

However, the presence of unexploited economies of scale, which became known as the "excess capacity theorem", gave rise to innumerable controversies in response to its apparent implication of free-market inefficiency. This controversy finally faded away when it became understood that, in a society that values diversity, there is a trade-off between economizing on resources by reducing the costs of producing existing products, and satisfying the desire for diversity by increasing the number of products. Optimum diversity occurs when existing products are produced at points to the left of the minimum-efficient scale; "excess capacity" is therefore not necessarily socially inefficient.

The attention paid to Chamberlin's model decreased later on, for two reasons worth of mentioning. First, it was shortly realized that virtually all industries containing a multitude of differentiated products contained only a few firms (See, for example, Markham (1964)). Thus, although the typical real-world set of differentiated products was a large group, the set of competing firms was a small group. Second, growth of interest in location theory showed that *localized*, rather than *generalized*, competition was also common in many industries where firms are differentiated by their geographic location. Although, for example, there are many drugstores in a city, each has a few nearby, and many distant, neighbours.

To understand the development of small group competition with differentiated products we need to begin with Cournot's (1838) model of quantity competition between oligopolists producing identical products. Then came Bertrand's (1883) formulation of the alternative of price competition showing that non-cooperative behaviour would drive prices down to marginal costs. Bertrand's critique of Cournot opened an important issue that still faces us: What conditions favour the use of either price or quantity as the strategic variable for oligopolistic competition?

The seminal article on competition between oligopolists producing differentiated products was Hotelling's (1929) "address branch model". Hotelling's starting point was Bertrand's critique of Cournot. He made a crucial change of assumptions by letting his duopolists compete to sell a differentiated rather than a homogeneous product.

Hotelling recognized that *space*, by its very nature, is a source of market power, and that localized competition between firms is common. Because market activities are performed at dispersed locations in space, each firm finds only a few rivals in its immediate neighbourhood; further away there might be more competitors, but their influence is weakened by the existence of *transportation costs.* Similarly, the firms do not consider all consumers to be alike; those who are far away from a firm will not buy from that firm because they have to pay too high a transportation cost. Accordingly, competition in space occurs "among few", thus leading to an analysis of the problem as a *strategic game.*

Hotelling's address branch model is better known as the *spatial competition* model. In this model, a population of consumers is spread out geographically, while firms selling a homogeneous product are located in the same area. Consumers have preferences with respect to the commodity made available by the firms either at the firms' or consumers' place (depending on who controls transport). Since the product is homogeneous, a basic feature of consumers' behaviour is that they buy from the firm charging the lowest full price, i.e., the price gross of transportation costs. As a result, the number of consumers patronizing a particular firm depends on its location and price policy, as well as on locations and price policies of competing firms established in the relevant area. This situation can be modelled typically as a *noncooperative game*, in which the players are firms, strategies are prices and/or locations, and the payoffs are profit functions.

The economic relevance of location games does not stem exclusively from their initial geographical set-up. Indeed, location problems are functionally related to many aspects of business competition in modern economies. First, the spatially dispersed nature of markets has a direct analog in industrial economies in the form of an industry with differentiated products. In the latter set-up, product substitutes are dispersed in a space of characteristics *à la* Lancaster, and the seller of a particular variant enjoys a quasi-monopolistic position relative to the consumers who most prefer it. The counterpart of transportation costs is the utility loss incurred by a consumer who does not find his "ideal product" on the market. Hence, modelling spatial competition extends immediately to modelling competition amongst firms producing differentiated commodities. In this domain, it has become useful to distinguish between market competition under horizontal and vertical product differentiation. Along several dimensions, the nature of competition turns out to be different under these two types of differentiation. Interesting enough, they have precise counterparts in spatial competition models. To horizontal product differentiation corresponds spatial competition with firms locating within the same subspace in which the consumers are located; we call the corresponding game *inside location game*. To vertical product differentiation corresponds spatial competition, where the sellers are located outside the residential area, like shopping centres set up along a road at the outskirts of a city. Given identical prices, all consumers prefer to buy from the shopping centre which is closest to the city. The corresponding game is called the *outside location game*.

Second, the location model is suited well for analysing *non-price competition*; firms are thus assumed to compete on other variables than prices; in particular, *product specification* appears as a basic decision variable. Marketers view the product sold by a firm as a mix of goods in conjunction with an array of services. The spatial analog of a firm choosing the attributes of a product defined as such, gives some competing facilities.

Third, although the objective in both pricing and product differentiation decisions is presumably to maximize profits, the time is different. It is not hard to change a pricing decision once it has been made. Companies can move from a high-profit margin, entry-encouraging price posture to a low-margin position virtually overnight. This is not nearly as true of product differentiation decisions. Once the firm has committed itself to a set of physical and subjective product attributes, months or even years may be required before it can escape that commitment. Although each decision evolves both short-run and long-run considerations, it is not too severe an oversimplification to suggest that products are chosen first and prices second. This leads to the so-called location-then-price and/or quality-then-price games.

Hotelling showed that if two competing firms are differentiated, either by having different geographic locations or by producing products differentiated in some one-dimensional characteristics space, price competition could keep prices high enough to cover capital costs, thus yielding a stable, long-run equilibrium. Lerner and Singer (1941) expanded Hotelling's model by increasing the number of firms beyond two. Smithies (1941) considered the consequence of altering Hotelling's restrictive demand assumption. Thirty years after his publication, however, only a modest amount of work could trace its linkage back to Hotelling's approach.

A renewed interest in addressing models of product differentiation was aided by the development of demand theory. The models developed by Lancaster (1966) and Quandt and Baumol (1966), in which consumers' preferences are defined over characteristics which themselves are embodied in goods, provided a structure in which the firm's decisions concerning product differentiation could be analysed in a meaningful way. Shortly after, Baumol (1967) studied a producer's optimal product design and observed that the new characteristic models provided "a promising approach to a problem that seems previously to have appeared to be intractable". Addressing models of competition between firms selling differentiated goods first concentrated on a finding developed from a variant of Hotelling's model, which Boulding (1966) christened the *principle of minimum differentiation*. Important contributions to this principle have been made by Gabszewicz and Thisse (1979), Champsaur and Rochet (1988), and Caplin and Nalebuff (1991). Consequent works have provided economically meaningful insights of the market differentiation behaviour of firms.

The history of standardization models

The revived development of horizontal and vertical differentiation has made these a popular framework to deal with various imperfect competition problems encountered in industrial organization. Interests spread quickly over many topics, such as *standardization*, and its implications to *antitrust markets* and *international trade policies*, studied in this monograph.

Having started with the early contribution of Hemenway (1975), the economics of standardization has since then evolved into a well-recognized area of industrial organization. The theoretical issues of standardization have been studied mainly in two frameworks: the network externalities and the mix-and-match framework.

In the presence of network externalities, each consumer's willingness to pay for a given good increases with the size of the network associated with this good. In the pioneering papers of Katz and Shapiro (1985), Farrell and Saloner (1985, 1985a) (henceforth KSFS) this positive relationship between consumers' utility and network size is taken exogenously. KSFS try to capture both direct and indirect network effects. Subsequent work has tried to provide firm foundations for indirect network effects. In Chou and Shy (1990) and Church and Gandal (1992a, 1993a) (henceforth CSCG), consumers derive utility from the consumption of a durable good and a set of complementary compatible components. In Matutes and Padilla (1994), network effects in the banking industry arise from reduced transportation costs. In this branch of research, differentiation models provide a useful framework to capture durable goods with indirect network externalities.

Through the mix-and-match approach, however, the differentiation framework established its importance in the economics of standardization. The work of Matutes and Regibeau (1988, 1992), and Economides (1989) (henceforth MRE) abstracts from network externalities and focuses on situations in which consumers derive utility from the use of a system consisting of a fixed number of compatible components.

Since a consumer's utility does not directly depend on the choices of other consumers, the mix-and-match framework emphasizes neither the role of consumers' expectations nor the lingering effects of past decisions. Moreover, with this approach compatibility between firms does not change the degree of differentiation between each firm's version of the same component. It only allows consumers to combine components from different manufacturers, resulting in a greater variety of available systems. Finally, consumers differ in their "ideal" specification for each component of the system. If the components from different brands are compatible, then some consumers choose to assemble components from different manufacturers in order to form a more satisfactory system than if they had been forced to use components from the same brand. Since consumers are willing to pay more for a system which is closer to their ideal, compatibility raises the willingness to pay of the consumers who prefer to "mix-and-match" but does not affect the willingness to pay of consumers who are happiest with the features of components from the same brand.

1.3.2 Insights

Horizontal differentiation

To understand the principle of differentiation, we discuss the *sequential game* introduced by Hotelling (1929).

There, price and location are chosen sequentially, where locations are chosen in the first stage and prices in the second stage of the game. Given that prices are chosen according to a noncooperative Nash equilibrium in pure strategies in the subgame consisting of the second stage (a Nash equilibrium in prices is a pair of prices such that no firm can gain by unilateral deviation), the corresponding equilibrium payoffs are well defined whenever the price equilibrium exists and is unique. In addition to relying on prices, the payoffs also depend upon the location choices of firms. Accordingly, they determine the payoff functions in the first stage of the game in which locations are chosen. A *subgame-perfect location-then-price equilibrium* captures the idea that, when firms choose their locations, they both anticipate the consequences of their choices on price competition. In particular, they are aware that this competition will be more severe if they locate closer to each other. Unfortunately, such an equilibrium can be determined only if, for any location choices of firms, there exists a unique price equilibrium in the second stage of the game; the payoff function would otherwise be either undefined, or multi-valued. Consequently, the focus moves to the existence and, a fortiori, to the uniqueness conditions of a price equilibrium. On the other hand, in some industries firms do not exert any control over their price because of either cartel agreements or price regulations by public authorities. Then, firms may compete on locations, in such a way that they obtain the largest possible sales. So, in order to derive a subgame-perfect location-then-price equilibrium, it is preferable to, first of all, fix one parameter while investigating another.

First, consider the *price stage*. In the price stage firms choose prices to maximize profits, given their locations. Gabszewicz and Thisse (1979) show that with linear transportation costs, there is a unique Nash equilibrium if the distance between the firms' locations is large enough. However, if the firms are too close, both firms have an incentive to charge a price such that the other firm must become inactive; there is, hence, no price equilibrium. They also show that with quadratic transportation costs, there exists a unique Nash equilibrium in prices for all possible locations of firms. The non-existence of a price equilibrium is caused by the non-quasi-concavity of the profit function (see Dasgupta and Maskin (1986)). Namely, if the firms are located too close to each other under linear transportation costs, the positive demand effect dominates the negative price effect. If the distance between the firms is large enough, profits are quasi-concave and the price effect dominates.

No general existence of price equilibrium in pure strategies can be proved for the location model. To date, the most general sufficient conditions on customer density and transportation cost functions have been derived by Champsaur and Rochet (1988). Alternatively, the most general sufficient conditions on demand functions which guarantee the existence and uniqueness of a price equilibrium in pure strategies have been provided by Caplin and Nalebuff (1991). Moreover, the conditions derived by Caplin and Nalebuff (1991) can be applied to models of differentiation with multi-dimensional attributes.

Next, consider the *location stage*. For cartels or regulated prices, locational competition between firms has been studied by Lerner and Singer (1937) and, more recently, by Eaton and Lipsey (1975) and Denzau, Kats and Slutsky (1985). Their results appeared not very robust to the specification of the model; in particular, they turn out to be very sensitive with respect to the customer distribution and the number of firms. To see this, let us assume that consumers are continuously distributed over the interval [0, 1]. Then, in the two-firm case, there exists a unique location equilibrium in pure strategies in which both firms are located at the median of the cumulative function. But for the three-firm case, no location equilibrium exists.

Somewhat surprisingly, the existence is restored for more than three firms. For the four-firm case, there exists a unique equilibrium for which two firms are located at the first quartile and the two others at the third one. For five-firm case, the equilibrium is unique and such that two firms are located at the first sextile, two others at the fifth one, and one firm is isolated at the market centre. If there are more than five firms, there exists a continuum of equilibrium configurations, characterized as follows:

- not more than two firms are at the same location;
- peripheral firms are paired with their neighbours;
- paired firms have equal sales;
- isolated firms have sales which are at least as large as those of paired firms but not more than twice as large.

Finally, we come to a complete description of an equilibrium of the sequential location-then-price game. A subgame-perfect Nash equilibrium for the two-stage location-then-price game is a pair of locations together with a pair of prices such that, given equilibrium prices in the second stage, no firm gains by changing its location unilaterally in the first stage, and no firm gains by changing its price unilaterally for any pair of locations.

Hotelling's (1929) finding that price competition between oligopolistic firms would result in consumers being offered products with an "excessive sameness" has become known as the principle of minimum differentiation. As this principle had been used widely, the conclusion of d'Aspremont, Gabszewicz and Thisse (1979) that this finding was invalid was quite a shock. Subsequent research tried to understand the invalidity as well as to find conditions to restore it.

First, we have the *maximum differentiation* result due to d'Aspremont, Gabszewicz and Thisse (1979) in case of quadratic transportation costs. If firms are allowed to locate outside the interval it is sometimes called *excessive differentiation* (see Tirole (1988)). Gabszewicz and Thisse (1992) show, for example, that transportation costs should be sufficiently convex in order to guarantee the existence of a price equilibrium for all location pairs.

Second, by generalizing the utility function used by Hotelling (1929), Economides (1986) shows that the degree of differentiation depends on the curvature of the transportation cost function. The principle of minimum differentiation does not hold for a family of utility functions having Hotelling's original utility function as a special case. Furthermore, the maximum differentiation result holds only if transportation costs are sufficiently convex.

Third, by generalizing the consumers' distribution function, Neven (1986) and Tabuchi and Thisse (1995), among others, show that the degree of differentiation depends on the specification of the distribution function.

Fourth, following Eaton and Lipsey (1975), a no-mill-price-undercutting assumption may be used (see Novshek (1980)). This means that each firm takes its competitor's price as given and refrains from setting a price that would eliminate the competitor's product. An alternative avoiding-price-war assumption is proposed in Hamilton and Thisse (1985), who show that over the domain of prices implied by this behavioural constraint, an equilibrium exists for all location pairs in Hotelling's model. In the location stage, the two firms establish themselves at their socially efficient locations. A related model is that of Friedman and Thisse (1993), describing the equilibrium behaviour in a model with a countably infinite succession of time periods. If equilibrium behaviour is such as to have firms collusively arrange a trigger strategy equilibrium in prices, and select their locations knowing that a particular such trigger strategy price equilibrium will ensue, the minimum differentiation result applies.

Finally, a different approach to the problem is the probabilistic one (for example, see de Palma, Ginsburgh, Papageorgiou, and Thisse (1985) or Anderson, de Palma, and Thisse (1992)). The point of departure for this approach is to recognize the fact that firms cannot determine *a priori* differences in consumers' tastes, so that they endow each consumer with a probabilistic choice rule. At the aggregate level, it is assumed that the probability functions predict the actual frequencies perfectly well. In this way, consumer demand is distributed smoothly between firms which, as a result, gives rise to overlapping market areas. It is shown that the principle of minimum differentiation holds when the degree of heterogeneity is sufficiently large. An alternative probabilistic approach is to consider mixed strategies. According to Osborne and Pitchik (1987), it turns out that, under appropriate conditions, a mixed strategy equilibrium may be viewed as a pure strategy equilibrium in a game of incomplete information.

Vertical differentiation

Recently, Gabszewicz and Thisse (1979, 1986), Mussa and Rosen (1978), and Shaked and Sutton (1982, 1983, 1987) developed a parallel variant of horizontal differentiation, namely, vertical differentiation. The study of vertical differentiation resembles that of horizontal differentiation closely. However, the markets captured by these two types of models are different, and the nature of competition shows some significant points of divergence.

First of all, Gabszewicz and Thisse (1986) compared the inside and outside location models. According to them, inside and outside locations have the analogs of horizontal and vertical differentiations, respectively. They show that when keeping location a parameter, more stability in price competition may be expected with vertically (outside locations) than with horizontally (inside locations) differentiated products.

Second, perhaps the most important and significant difference is that between the so-called "fragmentation" property in Hotelling's model of horizontal differentiation and the "finiteness" property in Shaked and Sutton's model (1983, 1987) of vertical differentiation. According to the fragmentation property, each firm earns a monopolistic profit under horizontal differentiation. With free entry, the size of fixed costs, relative to the size of the economy, determines the number of firms, and therefore the degree of market concentration. As the size of the economy increases, the level of market concentration falls. At the limit, the market is able to hold an arbitrarily large number of firms, each with a positive market share and a price exceeding unit variable cost. Hence, economies of scale become less of a barrier to entry in "large" economies. This property is fundamental: As firms become more closely spaced, price competition between them implies that prices approach the level of unit variable cost. It is this "Chamberlinian" configuration which forms the basis of the notion of "perfect monopolistic competition".

Under vertical differentiation, on the other hand, the finiteness property or market concentration holds; there exists an upper bound, independent of product qualities or market size, to the number of firms that are able to coexist with positive market shares and prices exceeding unit variable costs, at a Nash equilibrium in prices. The conditions required for this finiteness property are as follows:

1) Unit variable costs should increase relatively slowly as quality increases (which is especially true when a sunk cost is mainly incurred for quality improvement);

2) The proportionate rate of increase in fixed costs associated with a given increase in quality (measured in terms of consumers' willingness to pay) should be bounded from above for all qualities.

It is worth stressing that the finiteness property is rather strong. The upper bound depends only on the pattern of tastes and the income distribution and is independent of the qualities of the various products being offered. The mechanism through which the result comes about, is that whatever the set of products entered, competition between certain "surviving" products drives their prices down to a level where every consumer prefers either to make no purchase, or to buy one of these surviving goods at its equilibrium price, rather than switch to any of the excluded products, at any price sufficient to cover unit variable cost.

Standardization

The economics of standardization provides many insights into the preferences of both the firms and the government for standardization and into the underlying mechanism:

1) In the absence of network externalities, horizontally differentiated firms producing homogeneous goods prefer standardization, and standardization may survive in equilibrium. The social preference for standardization normally remains ambiguous, however.

2) An incumbent might want to commit himself to non-standardization in order to deter entry.

3) A higher degree of standardization may encourage or dissuade Research and Development (R&D) efforts – depending on whether the firm is a technological leader or follower and on when firms must commit to a standard. Likewise, *incentives* to reach standardization agreements may differ between firms (depending on their technological level) and do not necessarily remain constant through time.

4) The effects of traditional "strategic" trade policies depend crucially on the firms' abilities to commit to a network size. This suggests that the effect of trade protection might well depend on the particular trade instrument utilized. In particular, the relative effects of tariffs, as well as quantity based restrictions such as quotas, must be determined.

These insights depend critically on the underlying mechanisms of standardization. Standardization problems arise when system goods and/or complementary products are provided by competitors in the market. On the one hand, standardization can not internalize the complementarity between components of a system good or two complementary products of a producer. Under standardization, cutting the price of one good will increase the sales of all system goods using that component, or the sales of its complementary products, including system goods or complementary products produced by other firms. Since some of the benefits of the price cut will be appropriated by other firms, each firm will behave less aggressively than in the case of non-standardization. Therefore, prices are higher in the standardization case and consumer surplus is decreased. On the other hand, standardization makes it possible for consumers to combine components or use products from different firms, thereby increasing the varieties available to the consumers. As a result, consumer surplus is increased.

The mechanisms of standardization make the incentives of firms producing system goods, or complementary products, different from the single product case. Also different is the social welfare. Since standardization is a popularly observed economic phenomenon, it becomes important to further explore the implications of standardization.

1.4 Overview of the monograph

After having discussed above the fields to which the models analysed in this monograph relate, we give an overview of these models. The following five sub-sections briefly introduce the different economic issues that will be studied and developed in the research.

1.4.1 Vertical product differentiation and outside goods

Walking on the street or shopping in the supermarkets, one finds that a (Philips) shaver is available in many varieties and qualities; there are computers in many types (where a smaller, more powerful computer is preferred to a larger, less powerful one in general); on the automobile market, a Mercedes Benz is, for example, preferred to a Volvo, and a Volvo preferred to a Hyundai, etc. The qualities of many similar products are different, and even supermarkets themselves are differentiated and known by selling luxurious or cheap products.

The wide array of products in the market place is a response to the wide diversity of consumer tastes. The taste of a consumer may be influenced by his nature, by the occasion, or by his income. For example, someone with high income may prefer expensive commodities like Rolls-Royce, a Mercedes Benz car, and a large, comfortable house with a swimming pool and a big garden, etc. However, if one's income is low, luxury commodities might be less valuable and unaffordable, so cheap commodities are preferred. If individual consumers value additional quality by different amounts, then the possibility arises for different quality products to be priced at levels that induce positive sales; the market is segmented. Of course, if consumers differ only moderately, products might be expected to differ little in quality. Since price competition is usually more intensive for the less heterogeneous products, the number of products existing in equilibrium may be very restricted and may reflect more the range of differences between consumers, and thus the demand for this kind of variety, than the number of consumers.

Mussa and Rosen (1978), Gabszewicz and Thisse (1979, 1980), and Shaked and Sutton (1982, 1983) formalized these commonly observed markets as vertically differentiated. To illustrate, let us consider Shaked and Sutton (1982). Imagine that a number of firms are waiting to enter a certain market, in which there is a technologically feasible quality spectrum for them to choose for the quality specifications of their products. All firms know that their technologies allow them to choose any quality from the quality spectrum. However, they are also aware that the product specification involves R&D, is less flexible, and once it is chosen, will commit them to produce that kind of quality product for a certain period. In this period, each of them faces price competition. Prices are more flexible; they may be adjusted overnight. Moreover, no production costs are involved and all firms know that consumers' incomes are uniformly distributed over a certain range. Then, we are in a stylized world in which a number of firms seek to enter a market, each of them with a package of business strategies in hand, and being aware that all of them decide, first, on entry, and then, on product quality, and finally, on price.

Shaked and Sutton (1982) conclude that in this world competition between firms results in an upper bound of the number of firms enjoying positive market shares and profits. This reflects the fact that competition between the surviving "high quality' products drives their prices down to a point at which not even the "poorest" consumer prefers the (excluded) low quality product at price zero. As a result, only a certain number of high quality product firms survive. Moreover, they conjecture that this upper bound rises as the range of incomes increases, but is independent of the qualities supplied and of a small entry cost. This conjecture has been elaborated further in Shaked and Sutton (1983), which leads to the finiteness property.

Shaked and Sutton's (1982) pathbreaking work encourages us to amend it by adding certain elements to consider their influences on product differentiation. In Chapter 2 we are interested, on the one hand, in the existence and uniqueness of a market equilibrium configuration; we ask if monopoly could survive in the market. On the other hand, although the "outside goods" are normally neglected by successors in this tradition, we suspect that it may play an interesting and significant role in effecting product differentiation.

1.4.2 Cooperation and competition in a vertically differentiated duopoly

Cooperation can be achieved through (tacit) collusion. Collusion practices can be traced back to ancient Babylon, Greece and Rome. Adam Smith remarked sagely that "people of the same trade seldom meet together, even for merriment and diversion, but the conversation ends in a conspiracy against the public, or in some contrivance to raise prices." Industry profits can never be higher than when firms set prices at the monopoly level, that is, at the price that would be set if one profit-maximizing enterprise controlled the industry output. However, collusion to secure monopolistic prices and profits is a venerable, if not venerated, situation. Unsuccessful attempts at collusion may backfire – leading to price wars and heavy losses – not to mention prison terms and other legal sanctions that may arise in countries where collusive agreements are prohibited.

The fragility of nonbinding collusive agreements arises from two central problems. First, the colluding parties may have divergent ideas about appropriate price levels and market shares, making it difficult to reach an understanding respected by all. Second, when the group agrees to abide by a price close to the monopoly level, strong incentives are created for individual members to cheat on the agreement – that is, to increase their profits by undercutting the fixed price slightly, gaining additional orders at a price that still exceeds marginal cost.

As a result, firms have to make the best of an oligopolistic market structure and thus try to devise and maintain communication systems that permit behaviour to be coordinated in the common interest of the firms. The conflicts that inevitably arise must be resolved without resorting to price warfare. Adjustments to changes in demand and cost conditions must be made so as to elicit unanimous consent and minimize the risk that actions taken in the group's interest will be misinterpreted as Prisoner's Dilemma-style defecting or self-serving aggression. Collusion is communication par excellence, but it is generally illegal, and the tide of antitrust legislation is running against it in many industrialized countries. Firms have an understandable desire to find alternative means of coordinating their behaviour without running afoul of the law. One such means is collusive price leadership.

The concept of price leadership was formulated by Jesse Markham to characterise the kind of leadership especially apt to support a monopolistic solution to the oligopolists' pricing coordination problem. According to Markham (1951), collusive price leadership is most likely to emerge when (a) the industry is tightly oligopolistic, (b) sellers' products are close substitutes and their cost curves are similar, (c) there are barriers to entry of new rivals, and (d) demand for the industry's output is relatively inelastic.

The cigarette industry during the 1920s and 1930s affords a classic example of collusive price leadership used to establish a price structure that tended to yield maximum collusive profits. The Big Three (Reynolds, American, and Liggett & Myers), selling from 68 to 90 percent of industry output, mostly through their Camel, Lucky Strike, and Chesterfield brands, clearly recognised their mutual interdependence. The leading brands were quite similar physically; blindfold tests revealed that experienced smokers could not distinguish between them. There is no close substitute for cigarettes in the minds of most consumers, and so the cigarette manufacturers enjoyed considerable discretion in choosing an overall price level.

The 1933 departures from the leadership of the Big Three illustrate the high degree of coordination and retaliation displayed by firms selling cigarettes of different qualities. The increased prices by the Big Three, combined with the dire financial straits in which many cigarette smokers found themselves, opened up significant market penetration possibilities for firms selling cigarettes of inferior quality. With the standard brands selling at retail prices of up to fifteen cents per pack, these so-called ten-cent brands increased their market share from 1 percent in early 1931 to 23 percent in late 1932. In response, the Big Three counterattacked by reducing their prices and were largely successful; the market share of ten-cent brands dropped from 23 percent in November 1932 to 6 percent in May 1933. Having recovered much of the lost ground, the Big Three increased their prices again in January 1934 (but the increased price levels were lower than their original ones).

Another example is the American automobile industry. General Motors has long been acknowledged as price leader. Smaller firms such as American Motors experienced considerably greater latitude to reduce prices by as much as $200 relative to General Motors models without provoking retaliation. Reductions of similar magnitude on poorly selling Chrysler models, were also tolerated. However, when Chrysler offered substantial rebates to combat an industry-wide 1975 model-year sales slump, Ford and General Motors quickly retaliated to protect their market shares.

Traditionally, the principal occasion to list-price changes was the day on which new models were introduced, usually in September. Although General Motors was the price leader, production scheduling considerations often required the other producers to announce their new models, and hence their prices, before General Motors did. They then tried hard to anticipate GM's decisions and set their prices accordingly, but if GM's subsequent announcement brought surprises, they beat a hasty retreat, raising or lowering their prices in the desired relationship with those of General Motors.

These two examples show that (a) some oligopolistic markets are vertically differentiated; there exist quality leaders and followers, and (b) oligopolists may compete in collusive or even *semicollusive environments.* The semicollusive environments arise when firms compete in the first stage with respect to non-price variables such as advertising, capacity or R&D, or even product specification. As their positions in the markets become clear, they then collude on prices in the second stage. However, this collusion on prices is sustained by non-cooperative dynamic price competition. Price deviation by any side will trigger price retaliation, and price warfare will ensue. Then, questions arise about these collusive or semicollusive environments: What kind of prices can be sustained? How should firms specify their products' qualities? Chapter 3 will elaborate on these issues and answer these questions.

1.4.3 Product differentiation with concentrated consumer distributions

There are two important factors in Hotelling's (1929) analysis of a spatial duopoly, the transportation cost functions and the consumer distributions. While the first factor has been well analysed and understood following Gabszewicz and Thisse (1979, 1992), the location theorists are still confused by the second one. The problem is that, following

Hotelling's tradition, contributions have generally maintained the assumption of a uniform consumer distribution which, although convenient, is far from satisfactory. First, research in marketing has pointed out the existence of "consumer pockets" in the characteristics space, corresponding to customers whose preferences are clustered around some fashionable brands (see, for example, Kuchn and Day, 1962). Second, in the urban setting, it is well known that the distribution of households is concentrated around the central business district (see, for example, Clark, 1951). Finally, Hotelling's model carries over to a specific formulation of quality competition where consumers would prefer a higher quality if available at the same price. If one were to take a stand that a consumer's willingness to pay for quality depends on his income, then the density of a consumer's income distribution most probably shows an asymmetric single-peaked shape with most of the weight on the lower values.

In summary, increasing densities of consumers towards the centre seem intuitively more appropriate. Such an assumption captures the idea that economies can be gained from concentration (a (log-) normal distribution is an obvious candidate), and should yield a more realistic model. Accordingly, it seems important to analyse whether, and how, firms' competition is modified by the introduction of this assumption, as compared to the case of a uniform distribution.

However, being short of handy but powerful tools, successors have hardly touched this problem. Exceptions include Neven (1986), Caplin and Nalebuff (1991), and Goeree and Ramer (1995). In particular, Caplin and Nalebuff (1991) threw light on this issue and provided us the tool to attack this consumer distribution problem in Chapter 4. We shall thus analyse a location-then-price competition, which arises between duopolists when consumer density increases towards the centre.

1.4.4 Standardization and protection under international competition

Several network industries are global in scope. The most significant firms in personal computers, telecommunications, VCRs, cars, or numerically controlled machine tools compete worldwide, sometimes in markets with different government-imposed standards. Moreover, many government-imposed standards seem to intend to protect local producers from foreign competition. This "hidden" protectionism is problematic with regards to the General Agreement on Tariffs and Trade as well as to efforts of the International Organisation for Standardization (ISO) to harmonise standards across borders. Given the importance of these policy issues, it is surprising that the theoretical literature on compatibility or standardization has focused almost completely on closed economies.

It seems natural to extend market competition between systems from a domestic environment to an international one for the discussion of the economics of standardization. This aspect of standardization has been widely observed empirically (Nicolas, 1988). A typical example is the ISO, which works to harmonise standards internationally and is responsible, for example, for the Open Systems Interconnection reference model in mainframe computers.

Extending the literature to an international environment involves two main modifications. First, there are now both "domestic" and "foreign" firms. The crucial difference here is that the profits of foreign-owned firms do not contribute to the home country's welfare so that the optimal standardization policy of the home country might well differ from what it would be in a closed economy. Secondly, some of the markets in which foreign and domestic firms compete might be served through exports. This opens the door to a strategic use of trade-policy instruments such as tariffs, quotas, export taxes, or subsidies.

One situation we may envision is that in the computer, washing machine, or television industry, a developing country opens its doors to the outside world, particularly, to a developed country. The domestic firm has the disadvantage of producing a lower quality product. It has also some advantages, however, such as being protected by the government's tariffs or subsidies, and the first-mover advantage as an incumbent, etc. We are then led to a situation in which a domestic firm faces competition from a foreign firm under trade liberalisation and protection. The foreign firm is a production technology leader and entrant, while the domestic firm is a production technology follower, but incumbent. One characteristic of these industries is that manufacturers produce not only durable equipment but also repair services. For example, in the computer industry, the manufacturers produce not only personal computers but also software programmes such as spreadsheets, word processors, databases, communication software, and so on. We may call the equipment *hardware* and the repair parts, programmes and services *software*. We shall examine the trade-off between these advantages and disadvantages in Chapter 5, which will also analyse the impact of trade policies on the compatibility choices of firms and optimal trade policies.

1.4.5 Desirability of compatibility by durable-goods producers

Many products have little or no value in isolation, but generate value when combined with others. Examples include home audio or video components and programming, which together provide entertainment services; automobiles, repair parts and service, which together provide transportation services; camera bodies and lenses, which together provide photographic services; photocopiers/micrographic equipment and repair parts/service, which together provide photocopy services. These are all examples of products that are strongly complementary, although they need not be consumed in fixed proportions. We describe them as forming *systems*, which refers to collections of two or more components together with an interface that allow the components to work together. Following the American Supreme Court's (1992) terms, we refer *equipment markets* to the primary markets (where primary products are produced) and *aftermarkets* to the markets where "aftermarkets transaction" takes place. This aftermarkets transaction, as defined by Shapiro and Teece (1994), is any transaction with two characteristics: (a) the aftermarkets product or service is used together with a primary product, and (b) the aftermarkets product or service is purchased after the primary product. In the case of *Kodak*, for example, the *equipment markets* are for photocopiers and micrographic equipment, and the *aftermarkets* involve the parts and service needed to keep these machines in good running condition.

System goods markets with components selling in equipment markets and aftermarkets have at least three characteristics. First, aftermarkets might be proprietary because of intellectual property rights. Market power by equipment manufacturers in aftermarkets is more likely to arise if aftermarkets are proprietary. Second, system goods are complementary goods. The parts and service are complements to equipment in the economic sense: Lowering the price of equipment raises the demand for parts and service, and vice versa. As a general rule, there are economic benefits from coordinating the sale of complementary goods, very possibly within the same firm. Finally, a customer or buyer who owns one brand of machine may face high switching costs in adopting another brand because the buyer has made investments in brand-specific skills or complementary assets. As a consequence, the buyer may engage in an integrated assessment of the *life-cycle costs* of rival brands of equipment. That is, the buyer of durable goods takes into account not only the original purchase price of the equipment, but also the expected maintenance costs (including supplies, parts, and services) in his decision making.

Market competition between systems, as opposed to market competition between individual products, highlights some important issues of compatibility or standardization (we do not distinguish between them in this monograph). These issues include the following: (a) How will firms make compatibility decisions, which firms will seek compatibility, and which will not? (b) How do intellectual property rights influence compatibility choices? How are the private and social incentives to produce compatible systems compared? (c) An extension of the compatibility decision is its implications for antitrust.

These issues of compatibility emerge from distinguishing between the industrial market structures, for which the primary markets and the aftermarkets can follow several patterns. First, equipment and service markets can be both competitive (telephones, fax machines); or both can be monopolized, either by the same firm or by separate firms. It is also possible for the primary markets to be competitive and the aftermarkets monopolized. If a single firm were to develop a proprietary technology to serve refrigerators in compliance with new environmental restrictions, that firm could conceivably monopolize the refrigerator service business, even if sales of refrigerators is competitive. The fourth logical possibility, a monopolized equipment market and competitive aftermarkets, arise if an equipment manufacturer has monopoly power and many firms service its equipment.

Many studies have focused on the fourth case. The central question asked refers to whether a firm could transfer his monopoly power from his equipment market over to his aftermarkets through "tying" when his equipment market is monopolised while the aftermarkets are competitive. A firm engages in *tying* when it makes the sale (or price) of one of its products conditional upon the purchaser also buying some other products from it. The "leverage theory" of tying says that tying provides a mechanism whereby a firm with monopoly power in one market can use the leverage provided by this power to foreclose sales in, and thereby monopolize, a second market. However, Director and Levi (1956), Bowman (1957), and Posner (1976) demonstrated the opposite and established the idea that "a monopolist only gets monopoly profits once". Thus, alternative explanations for tying contend that if a monopolist does employ tying, his motivation could be price discrimination (Bowman, 1957), achieving economics of joint sales, protection of goodwill, risk sharing, and cheating on a cartel price. Almost inadvertently, the more formal economics literature on tying (Burstein, 1960; Blair and Kaserman, 1978; Schalensee, 1982) has reinforced this view as a result of its exclusive focus on price discrimination motivations for practice. Recently, Whinston (1990) argued that tying can indeed serve as a mechanism for leveraging market power (provided the existence of an oligopolistic market structure and scale economies). The argument is foreclosure, which says that if tying causes competitive firms to leave the competitive market, then a monopolist can raise the price of the (formerly) competitive goods.

There are also studies on the third case that ask the reversed question: will competition between equipment manufacturers inevitably preclude any finding of monopoly power in derivative aftermarkets? The answer to this question provided by the economic literature is "no". For example, Borenstein, MacKie-Mason and Netz (1996), Blair and Herndon (1996), and Shapiro and Teece (1994) demonstrated that equipment manufacturers have incentives to exercise market power in their tied aftermarkets. But at the same time, in two later papers it is argued that this power of aftermarkets should not be an antitrust concern.

However, the more realistic and important case that has not been studied refers to the one in which equipment markets and aftermarkets are both locally monopolised. The question that may be then asked is whether firms have incentives to tie their aftermarkets with equipment markets and what are the consequences for social welfare. We shall formulate these markets and analyse these issues in Chapter 6.

In Chapter 6, we recognize that locally monopolised equipment markets and aftermarkets share the similarity with horizontally differentiated markets, and that the "mix-and-match" approach provides a suitable framework for the formulation of these markets. We envision a world in which consumers benefit from the use of a system that consists of a fixed set of compatible components. In this context, compatibility means that a consumer can combine components from different producers. This results in a large variety of goods – although each firm's realisation of the same component is taken as given. However, the larger the number of varieties, the more likely it is that a consumer is able to buy her most preferred version of a system good. The willingness to pay will increase for those consumers who benefit from the mix-and-match possibility. Neither direct nor indirect network effects are considered. The utility of the consumer does not depend on the choices of other consumers, at least not directly. With reference to mix-and-match compatibility, important problems such as antitrust implications will be discussed.

1.4.6 Concluding remarks

This thesis analyses why products become increasingly heterogenous in both their physical and qualitative appearances in the modern market economy. Among the important causes, competition from outside goods, non-uniform but concentrated consumer distributions, and competition and cooperation, are studied for the demonstration of their economic implications. The applications are twofold. First, there are the incentives of durable-goods producers to tie their aftermarkets with their primary markets, and the social consequences of that action. Second, there are the international trade policies of standardization. The analysis focuses on whether a domestic durable-goods producer, being a quality follower and incumbent, will agree on standardizing its products with a foreign durable-goods producer, under international competition and government protection.

Detailed discussions will be provided in the next five chapters, which are modified versions of Han and Webers (1996) and Han (1995, 1996, 1997, 1997). The main conclusions of the research are as follows.

First, consider a vertically differentiated duopoly *à la* Shaked and Sutton (1982), where the quality spectrum from which the firms can choose is narrow. Then, the two firms will be squeezed into a restricted product space, and competition between the two firms will be so strong that the effect of outside goods is strictly dominated and the two firms always try to differentiate their products maximally within the given quality spectrum. On the other hand, when the feasible quality spectrum is large, the two firms will have sufficient room in order to make choices of their product qualities. In this case, competition between the two firms becomes moderate and the effect of outside goods arises. Without cost differences between the two firms, the standard result is that the lower quality product producer (firm 1) wants more product differentiation, since this relaxes price competition and increases profits (Tirole, 1988). When the effect of outside goods increases, however, the competition that firm 1 faces increases also. Moreover, this effect of outside goods is stronger for firm 1 than for the higher quality product producer (firm 2). As a result, the higher the quality of outside goods, the stronger becomes the competition that firm 1 will face, and the more product differentiation that firm 1 wants from firm 2. Moreover, although the degree of product differentiation increases with the effect of outside goods, the equilibrium levels of prices and profits of the two firms decrease because of the increased competition.

Second, consider the similar framework of a vertically differentiated duopoly, in which the quality of outside goods is assumed zero, but the two firms may have more strategic variables, such as qualities and prices, at their disposal. Then, three cases arise: (a) cooperation on both qualities and prices, (b) competition on qualities but cooperation on prices, (c) competition on both qualities and prices. The analysis shows that the two firms will cooperate on both qualities and prices and differentiate their products maximally.

Third, consider two firms in both inside and outside location games, which are analogs of horizontal and vertical product differentiations, respectively, corresponding to location theory. The concentrated consumer distribution creates a market retention force in the inside location game, and increases the asymmetry between the firms in the outside location game. As a result, the firms tend to move toward the inside of the market and decrease their product differentiation in the inside location game, while they try to move apart and increase their product differentiation in the outside location game.

Fourth, consider firms producing system goods. A system good consists of several components. Components are useless unless they form the system good. The situation considered is that a domestic firm producing system goods faces competition from a foreign firm producing higher quality of system goods, and is protected by the government through trade policies, such as tariffs. The issue arisen is whether the two firms will agree on standardizing their components given government protection. We show that trade liberalization is associated with standardization of the components of the system goods, while protectionism may lead to non-standardization when consumers' taste parameters are independent. When consumers' taste parameters are identical, however, the standardization choices of firms are independent of the government trade policies. We show also that neither welfare nor the optimal tariff could be changed by the government's precommitment to a given tariff level, and standardization is always implemented by the government.

Finally, consider durable-goods industries with aftermarkets. Then, durable-goods producers or manufacturers may have incentives to use the aftermarkets price as strategic variable to increase profits, which may cause antitrust concerns. For the duopoly case, the analysis shows that durable-goods producers will prefer to compete on their aftermarkets rather than to protect their proprietary aftermarkets through tying if the consumer's reservation price is sufficiently low. If the consumer's reservation price is sufficiently high, however, the two producers may prefer either to tie or to compete on their aftermarkets – provided that the aftermarket profit is discounted sufficiently, and tying is particularly preferred in this case if these two firms could coordinate on it. If the aftermarket profit is sufficiently valued, however, no agreement can be reached between the two firms. Moreover, the social optimum may be consistent with the firms' choices of tying.

1.5 Preliminaries: Dynamic games of complete information

The games analysed in this monograph are dynamic games of complete (but imperfect) information, the key features of which are that (a) the moves are in sequential stages but simultaneous within each stage, (b) all previous moves are observed before the next move is chosen, and (c) the players' payoffs from each feasible combination of moves are common knowledge. The fact that moves within each stage are made simultaneously means that the games have imperfect information. The *normal-form game* and *Nash equilibrium* form the basis of this dynamic game.

The normal-form representation of a game specifies the following: (a) the players in the game, (b) the strategies available to each player, and (c) the payoff received by each player for each combination of strategies that could be chosen by the players. In an n-player game, the players are numbered from 1 to n and an arbitrary player is called player i. Let S_i denote the set of strategies available to player i (called i's *strategy space*), and let s_i denote an arbitrary element of this set. Write $s_i \in S_i$ to indicate that the strategy

s_i is a member of the set of strategies S_i and let $(s_1, \ldots, s_n)$ denote a combination of strategies, one for each player, and let u_i denote player i's *payoff function:* $u_i(s_1, \ldots, s_n)$ is the payoff to player i if the players choose strategies $(s_1, \ldots, s_n)$.

Definition 1.5.1 *The* **normal-form representation** *of an n-player game $G = \{S_1, \ldots, S_n; u$ specifies the players' strategy spaces $S_1, \ldots, S_n$ and their payoff functions $u_1, \ldots, u_n$.*

The definition of a Nash equilibrium of a game in normal form is as follows.

Definition 1.5.2 *In the n-player normal-form game $G = \{S_1, \ldots, S_n; u_1, \ldots, u_n\}$, the strategies $(s_1^*, \ldots, s_n^*)$ are a* **Nash equilibrium** *if, for each player i, s_i^* is player i's best response to the strategies specified for the other players, $(s_1^*, \ldots, s_{i-1}^*, s_{i+1}^*, \ldots, s_n^*)$:*

$$u_i(s_1^*, \ldots, s_{i-1}^*, s_i^*, s_{i+1}^*, \ldots, s_n^*) \geq u_i(s_1^*, \ldots, s_{i-1}^*, s_i, s_{i+1}^*, \ldots, s_n^*)$$

for every feasible strategy s_i in S_i; that is, s_i^* solves

$$max_{s_i \in S_i} u_i(s_1^*, \ldots, s_{i-1}^*, s_i, s_{i+1}^*, \ldots, s_n^*).$$

1.5.1 Two-stage games of complete but imperfect information

We first analyse the following simple game, which will apply to most of our economic problems analysed in this monograph, and we call it, following Gibbons (1992), a two-stage game of complete but imperfect information:

1. Players 1 and 2 simultaneously choose actions a_1 and a_2 from feasible sets A_1 and A_2, respectively.

2. Players 1 and 2 observe the outcome of the first stage, (a_1, a_2), and then simultaneously choose actions a_3 and a_4 from feasible sets A_3 and A_4, respectively.

3. Payoffs are $u_i(a_1, a_2, a_3, a_4)$ for $i = 1, 2$.

In case of a two-stage location-then-price or quality-then-price game, the players are firms, the actions in the first stage are *locations* or *qualities* and the actions in the second stage are *prices*. We define h^2, the history at the end of stage 2, to be the sequence of actions in the previous two periods, $h^2 = (a_1, a_2, a_3, a_4)$. Since h^2 by definition describes an entire sequence of actions from the beginning of the game on, the set of all possible histories at the end of stage 2 is the same as the set of all possible outcomes when the game is played.

We solve a game from this class by using an approach in the spirit of backwards induction. In the first step in working backwards from the end of the game, we solve a simultaneous-move game between players 1 and 2 in stage two, given the outcome from stage one. To keep things simple, we assume that for each feasible outcome of the first-stage game, (a_1, a_2), the second-stage game that remains between players 1 and 2 has a unique Nash equilibrium, denoted by $(a_3^*(a_1, a_2), a_4^*(a_1, a_2))$.

If players 1 and 2 anticipate that their second-stage behaviour will be given by $(a_3^*(a_1, a_2), a_4^*(a_1, a_2))$, then the first-stage interaction between players 1 and 2 amounts to the following simultaneous-move game:

1. Players 1 and 2 simultaneously choose actions a_1 and a_2 from feasible sets A_1 and A_2, respectively.

2. Payoffs are $u_i(a_1, a_2, a_3^*(a_1, a_2), a_4^*(a_1, a_2))$ for $i = 1, 2$.

Suppose (a_1^*, a_2^*) is the unique Nash equilibrium of this simultaneous-move game. We call $(a_1^*, a_2^*, a_3^*(a_1^*, a_2^*), a_4^*(a_1^*, a_2^*))$ the *subgame-perfect equilibrium* outcome of this two-stage game. This equilibrium concept has both attractive and unattractive features. Players 1 and 2 should not believe a threat by opponent that the rival will respond with actions that are not a Nash equilibrium in the remaining second-stage game, because when play actually reaches the second stage at least one of them will not want to carry out such a threat (exactly because it is not a Nash equilibrium of the game that remains at that stage).

1.5.2 Finite-stage games of complete but imperfect information

In some situations, the economic problems analysed in this monograph can be modelled by allowing a longer sequence of stages through allowing players to move in more than two stages. For this, we need a definition of subgame-perfect equilibrium of finite-stage games of complete but imperfect information.

Let $I = \{1, 2, \ldots, n\}$ be the set of n players in the finite-stage game G^F, where F is the number of stages. In the first stage of G^F, each player $i \in I$ simultaneously chooses actions from the choice set $A_i^1(h^0)$, where $h^0 = \emptyset$ is the *history* at the start of the game. At the end of each stage, all players observe the actions chosen in that stage. Let $a^1 = (a_1^1, \ldots, a_n^1)$ be the action profile in stage 1, with $a_i^1 \in A_i^1(h^0)$ the action taken by player $i \in I$ in this stage. We define h^1, the history at the start of the second stage or at the end of the first stage, to be the action in the previous period, i.e. $h^1 = a^1$ given that $h^0 = \emptyset$. At the beginning of stage 2, the players know history h^1. In general, the actions player $i \in I$ has available in stage 2 depend on what has happened previously, so we let $A_i^2(h^1)$ denote the possible second-stage actions when the history is h^1. In the second stage of G^F, each player $i \in I$ simultaneously chooses actions from the choice set $A_i^2(h^1)$, where h^1 is the history at the start of the second stage. Let $a^2 = (a_1^2, \ldots, a_n^2)$ be the action profile in stage 2, and so on. In this setting, a *pure strategy* for player $i \in I$ is simply a contingent plan of how to play in each stage $k \in K = \{1, \ldots, F\}$ for every possible history h^{k-1}. If we let H^{k-1} denote the set of all histories at stage k, and

$$A_i^k(H^{k-1}) = \bigcup_{h^{k-1} \in H^{k-1}} A_i^k(h^{k-1}),\ k \in K,$$

then a pure strategy for player $i \in I$ is a set of maps $s_i = \{s_i^1, \ldots, s_i^F\}$, where each s_i^k, $k \in K$, maps H^{k-1} into the set of player i's feasible actions, $A_i(H^{k-1})$. The sequence of action profiles generated by such strategies are found then as follows. The action profile is $a^1 = s^1(h^0)$ in stage 1, the action profile is $a^2 = s^2(h^1)$ in stage 2, and so on. The sequence $(a^1, \ldots, a^F)$ is called the *path* of the strategy profile. Since a terminal history represents an entire sequence of play, we can represent player i's payoff or *profit* as a function $\Pi_i : H^F \mapsto \mathbb{R}$.

Defining subgame-perfection requires a few preliminary steps. First, since all players know the history h^{k-1} of moves before stage $k \in K$, we may consider the game from stage k on with history h^{k-1} as a game in its own right, which we denote $G(h^{k-1})$. To define the payoff functions for this game, note that if the action profiles in stages 1 to F are a^1, ..., a^F, the history at the end of stage F will be $h^F = (a^1, \ldots, a^F)$ and so the payoffs are $\Pi_i(h^F)$ for player $i \in I$. For player $i \in I$, strategies in $G(h^{k-1})$ are simply maps from the set of histories to the set of actions, where the only histories we need to consider are those consistent with h^{k-1}. So now we can speak of the Nash equilibria of the stage game $G(h^{k-1})$, $k \in K$.

Moreover, any strategy profile $s = (s_1, \ldots, s_F)$ of the game G^F induces a strategy profile $s \mid h^{k-1}$ on any stage game $G(h^{k-1})$, $k \in K$, in the following way. For each player $i \in I$, let $s_i \mid h^{k-1}$ denote the restriction of s_i to the histories consistent with h^{k-1}, $k \in K$.

Definition 1.5.3 *A strategy profile s of a finite-stage game G^F with observed actions is a subgame-perfect Nash equilibrium if, for every $h^{k-1} \in H^{k-1}$, $k \in K$, the restriction $s \mid h^{k-1}$ to the game $G(h^{k-1})$ is a Nash equilibrium of $G(h^{k-1})$.*

The subgame-perfect Nash equilibrium separates the "reasonable" Nash equilibria from the "unreasonable" ones (see Selten (1965)). In finite-stage games with observed actions, subgame-perfection requires that the restrictions of the strategy profile yield a Nash equilibrium from the start of each stage for any history up to that stage. Because the game has a fixed finite number of stages, we are able to characterise the subgame-perfect Nash equilibria using backward induction. The strategies in the last stage must be a Nash equilibrium of the corresponding one-shot simultaneous-move game, and for each history h^k we replace the last stage by one of its Nash-equilibrium payoffs. By repeating this step for $k = F, \dots, 1$, we reach eventually the first stage, with history h^0. From this we can easily derive the subgame-perfect Nash equilibria.

1.5.3 Semi-collusive games of complete but imperfect information

The semi-collusive games are an extension of finite-stage games with complete but imperfect information. The first stages involve simultaneous moves by players for non-price competition, and the remaining stages are simultaneous moves for price competition repeated infinitely. Tacit collusion on prices may emerge from this repeated price competition if rivals discount their future values and manipulate some well specified strategies. Suppose players compete on the non-price factor, such as qualities, in the first stages but anticipate that they will collude on the price in the later stage. Then, it seems that these players face a finite-stage game in which they play non-cooperatively until the last stage – and then cooperatively in the final stage. To put it formally, we need first to define the *present value* of an infinite sequence of payoffs.

As first introduced in Rubinstein's (1982) bargaining model, a discount factor $\delta = 1/(1+r) \in (0,1)$ is the value today of a dollar to be received one stage later, where $r \in (0,1)$ is the interest rate. Given a discount factor and a player's payoffs from an infinite sequence of stage games, we are able to compute the present value of those payoffs: the lump-sum payoff that could be put in the bank now so as to yield the same bank balance at the end of the sequence.

Definition 1.5.4 *Given a discount factor δ, the* **present value** *of the infinite sequence of payoffs $\pi_1, \pi_2, \pi_3, \dots$ is*

$$\pi_1 + \delta\pi_2 + \delta^2\pi_3 + \ldots = \sum_{t=1}^{\infty} \delta^{t-1}\pi_t.$$

Let be given a stage game $G = \{A_1, \dots, A_n; u_1, \dots, u_n\}$, being a static game of complete information in which players 1 through n simultaneously choose actions a_1 through a_n from the action spaces A_1 through A_n, respectively, and get payoffs $u_1(a_1, \dots, a_n)$ through $u_n(a_1, \dots, a_n)$, correspondingly. We can then define an infinitely repeated game.

Definition 1.5.5 *Given a stage game G, let $G(\infty, \delta)$ denote the* **infinitely repeated game** *in which G is repeated forever and the players have common discount factor $\delta \in (0,1)$. At each stage t, the outcomes of the $t-1$ preceding plays of the stage game are* *observed before the $t-th$ stage begins. Each player's payoff in $G(\infty, \delta)$ is the present value of the player's payoffs from the infinite sequence of stage games.*

In the infinitely repeated game $G(\infty, \delta)$, the *history of play through stage* t is the record of the players' choices in stages 1 through t. The players might have chosen $(a_{11}, \ldots, a_{n1})$ in stage 1, $(a_{12}, \ldots, a_{n2})$ in the stage 2, ..., and $(a_{1t}, \ldots, a_{nt})$ in stage t, for example, where for each player i and stage s the action a_{i_s} belongs to the action space A_i.

Definition 1.5.6 *In the infinitely repeated game $G(\infty, \delta)$, a player's* **strategy** *specifies the action the player will take in each stage, for each possible history of play until the previous stage.*

Definition 1.5.7 *In the infinitely repeated game $G(\infty, \delta)$, a player's* **Bertrand trigger strategy** *is the strategy that each player begins the infinitely repeated game by charging a cooperative price, and then cooperates in each subsequent stage game if and only if all of the other players have cooperated at all previous stages; otherwise, each will retaliate by charging a Bertrand competitive price for ever.*

Then we are ready to define a semi-collusive game as follows.

Definition 1.5.8 *A semi-collusive game is a dynamic game in which the first stages involve non-price competition and all subsequent stages involve price collusion sustained by Bertrand trigger strategies for all players.*

To define a semi-collusive equilibrium, we first introduce the *subgame* of an infinitely repeated game (see Gibbons (1992)):

Definition 1.5.9 *In the infinitely repeated game $G(\infty, \delta)$, each* **subgame** *beginning at stage $t+1$ is identical to the original game $G(\infty, \delta)$. As in the finite-horizon, there are as many subgames beginning at stage $t+1$ of $G(\infty, \delta)$ as there are possible histories of play through stage t.*

We are now ready for the definitions of a subgame-perfect Nash equilibrium and a semi-collusive equilibrium. In a dynamic game, a Nash equilibrium is a collection of strategies, one for each player, such that each player's strategy is the best response to the other players' strategies.

Definition 1.5.10 *(Selten, 1965) A Nash equilibrium is* **subgame perfect** *if the players's strategies constitute a Nash equilibrium in every subgame.*

Definition 1.5.11 *A semi-collusive equilibrium is a* **subgame perfect Nash equilibrium** *of the semicollusive game.*

References

ANDERSON, S.P., A., DE PALMA AND J.-F., THISSE, 1992, *Discrete Choice Theory of Product Differentiation*, Cambridge: MIT Press.

BAUMOL, W.J., 1967, "Calculation of optimal product and retailer characteristics: The abstract product approach", *Journal of Political Economy*, 75, 674-685.

BERTRAND, J., 1883, "Théorie mathématique de la richesse sociale", *Journal des Savants*, 499-508.

BLAIR, R.D. AND D.L., KASERMAN, 1978, "Vertical integration, tying and antitrust policy", *American Economic Review*, 68, 397-402.

BLAIR, R.D. AND J.B., HERNDON, 1996, "Restraints of Trade by Durable Good Producers", *Review of Industrial Organization*, 11, 339-353.

BORENSTEIN, S., J.K., MACKIE-MASON AND S.J., NETZ, 1996, "Exercising Market Power in Proprietary Aftermarket", Manuscript, University of California Energy Institute.

BOULDING, K., 1966, *Economic Analysis*, New York: Harper.

BOWMAN, W.S., 1957, "Tying arrangements and the leverage problem", *Yale Law Review*, 67, 19-36.

BURSTEIN, M.L., 1960, "The economics of tie-in sales", *Review of Economics and Statistics*, 42, 68-73.

CAPLIN, A. AND B., NALEBUFF, 1991, "Aggregation and Imperfect Competition: On the Existence of Equilibrium", *Econometrica*, 59, 25-59.

CHAMBERLIN, E.H., 1933, *The Theory of Monopolistic Competition*, Cambridge: Harvard University Press.

CHAMPSAUR, P. AND J. -CH., ROCHET, 1988, "Existence of price equilibrium in a differentiated industry", INSEE, Paris, Working paper 8801.

CHOU, C. AND O., SHY, 1990, "Network effects without network externalities", *International Journal of Industrial Organization*, 8, 259-270.

CHURCH, J. AND N., GANDAL, 1992a, "Network effects, software provision, and standardization", *Journal of Industrial Economics*, 40, 85-104.

CHURCH, J. AND N., GANDAL, 1993a, "Complementary network externalities and technological adoption", *International Journal of Industrial Organization*, 11, 239-260.

COURNOT, A., 1838, *Recherches sur les Principes Mathématiques de la Théotie des Richesses, (English edition, Researches into the Mathematical Principles of the Theory of Wealth, N. Bacon (ed.))*, Macmillan, New York, 1897.

DASGUPTA, P. AND E., MASKIN, 1986, "The existence of equilibrium in discontinuous economic games, 1: Theory", *Review of Economic Studies*, 53, 1-26.

D'ASPREMONT, C., J.J., GABSZEWICZ AND J.-F., THISSE, 1979, "On Hotelling's stability in competition", *Econometrica*, 47, 1145-1150.

DAVIDSON, C. AND R., DENECKERE, 1990, "Excess capacity and collusion", *International Economic Review*, 31, 521-541.

DE BIJL, P., 1995, *Essays in Industrial Organization and Management Strategy*, Chapter 6, Ph.D Thesis, Tilburg University, Tilburg.

DENECKERE, R. AND M., ROTHSCHILD, 1992, "Monopolistic competition and preference diversity", *Review of Economic Studies*, 59, 361-373.

DENZAU, A., A., KATS AND S., SLUTSKY, 1985, "Multi-agent equilibria with market share and ranking objectives", *Social Choice and Welfare*, 2, 95-117.

DE PALMA, A., V., GINSBURGH, Y.Y., PAPAGEORGIOU AND J.-F., THISSE, 1985, "The principle of minimum differentiation holds under sufficient heterogeneity", *Econometrica*, 53, 767-781.

DIAMOND, P.A. AND J.E., STIGLITZ, 1974, "Increases in risk and risk-aversion", *Journal of Economic Theory*, 8, 337-60.

DIRECTOR, A. AND E., LEVI, 1956, "Law and the future: Trade regulation", *Northwestern University Law Review*, 51, 281-96.

DONNENFELD, S. AND S., WEBER, 1992, "Vertical product differentiation with entry", *International Journal of Industrial Organization*, 10, 449-472.

EATON, B.C. AND R.G., LIPSEY, 1975, "The principle of minimum differentiation reconsidered: Some new developments in the theory of spatial competition", *Review of Economic Studies*, 42, 27-49.

ECONOMIDES, N., 1986, "Minimal and maximal product differentiation in Hotelling's duopoly", *Economics Letters*, 21, 67-71.

ECONOMIDES, N., 1989, "Desirability of compatibility in the absence of network externalities", *The American Economic Review*, 79, 1165-1181.

FARREL, J. AND G., SALONER, 1985, "Standardization, compatibility and innovation", *The RAND Journal of Economics*, 16, 70-83.

FARREL, J. AND G., SALONER, 1986a, "Installed base and compatibility: Innovation, product preannouncements, and predation", *American Economic Review*, 76, 940-955.

FARREL, J. AND C., SHAPIRO, 1988, "Dynamic competition with switching costs", *The RAND Journal of Economics*, 19, 123-137.

FERSHTMAN, C. AND N., GANDAL, 1994, "Disadvantageous semicollusion", *International Journal of Industrial Organization*, 12, 141-154.

FRIEDMAN, J.W. AND J.-F., THISSE, (1993), "Partial collusion fosters minimum product differentiation", *RAND Journal of Economics*, 24, 631-645.

GABSZEWICZ, J. AND J.-F., THISSE, 1979, "Price competition, quality and income disparities", *Journal of Economic Theory*, 20, 340-359.

GABSZEWICZ, J.J. AND J.-F., THISSE, 1986, "On the nature of competition with differentiated products", *The Economic Journal*, 96, 160-172.

GABSZEWICZ, J.J. AND J.-F., THISSE, 1992, "Location", in R.J. Aumann and S. Hart (eds.), *Handbook of Game Theory with Economic Applications*, **Vol. I**, Amsterdam: Elsevier, 281-304.

GIBBONS, R., 1992, *A Primer in Game Theory*, Hemel Hempstead: Harvester Wheatsheaf.

GOEREE, J. AND R., RAMER, 1995, "Exact Solutions of Location Games", Memeo, Department of Econometrics, University of Amsterdam.

HÄCHNER, J., 1994, "Collusive pricing in markets for vertically differentiated products", *International Journal of Industrial Organization*, 12, 155-177.

HAN, X. AND H., WEBERS, 1996, "A comment on Shaked and Sutton's model of vertical product differentiation", CentER Discussion paper, No. 9666, Tilburg University.

HAN, X., 1995, "Competition and coorperation in a vertically differentiated duopoly", paper presented at 22nd E.A.R.I.E. Annual Conference, September 3-9, 1995, Juan les Pins/Sophia Antipolis, France.

HAN, X., 1996, "Product differentiation with concentrated consumer distributions", paper presented at ESEM96, July 10-12, 1996, University of Western Australia, Perth, Australia.

HAN, X., 1997, "Standardization and protection under international competition", paper presented at 24nd E.A.R.I.E. Annual Conference, August 31-September 3, 1997, Leuven, Belgium.

HAN, X., 1997, "Desirability of tying by durable-goods producers", paper accepted by ESEM97, July 10-12, 1997, University of Melbourne, Melbourne, Australia.

HAMILTON, J.H. AND J.-F., THISSE, 1985, "Equilibrium in Hotelling's model under conjecture that avoids price war", CORE Discussion paper 8534, Université Catholique de Louvain, Louvain-la-Neuve.

HEMENWAY, D., 1975, *Industrywide voluntary product standards*, Cambridge: Ballinger.

HOTELLING, H., 1929, "Stability in competition", *Economic Journal*, 39, 41-578.

KATZ, M. AND C., SHAPIRO, 1985, "Network externalities, competition, and compatibility", *American Economic Review*, 75, 424-40.

KLARK, C., 1951, "Urban population densities", *Journal of the Royal Statistical Society*, A 14, 490-496.

KLEMPERER, P., 1995, "Competition when consumers have switching costs: An overview with applications to industrial organization, macroeconomics, and international Trade", *Review of Economic Studies*, 62, 515-539.

KLEMPERER, P., 1987b, "The Competitiveness of markets with switching costs", *The RAND Journal of Economics*, 18, 138-150.

KLEMPERER, P., 1987a, "Markets with consumer switching costs" , *The Quarterly Journal of Economics*, 102, 375-394.

KUCHN, A.A. AND R.L., DAY, 1962, "Strategy of product quality", *Harvard Business Review*, 40, 100-110.

Lancaster, K.J., 1966, "A new approach to consumer theory" , *Journal of Political Economy*, 74, 132-57.

Leland, H.E., 1972, "The Theory of the firm facing uncertainty demand", *The American Economic Review*, 62, 278-91.

Lerner, A. and H., Singer, 1941, "Some notes on duopoly and spatial competition", *journal of Political Economy*, 45, 423-439.

Markham, J.W., 1951, "The nature and significance of price leadership", *American Economic Review*, 41, 891-905.

Markham, J.W., 1964, "The theory of monopolistic competition after thirty years", *American Economic Review*, 54, 53-55.

Matsui, A., 1989, "Consumer-benefitted cartels under strategic capital investment competition", *International Journal of Industrial Organization*, 7, 451-470.

Matutes, C. and J., Padilla, 1994, "Shared ATM networks and banking competition", *European Economic Review*, 38, 1113-1138.

Matutes, C. and P., Regibeau, 1988, "'Mix and Math': Product compatibility without network externalities", *RAND Journal of Economics*, 19, 221-234.

Matutes, C. and P., Regibeau, 1992, "Compatibility and bundling of complementary goods in a duopoly", *The Journal of Industrial Economics*, 40, 37-54.

Motta, M., 1994, "International trade and investments in a vertically differentiated industry", *International Journal of Industrial Organization*, 12, 179-196.

Mussa, M. and S., Rosen, 1978, "Monopoly and product quality", *Journal of Economic Theory*, 18, 301-317.

Neven, D. J., 1986, "On Hotelling's competition with non-uniform customer distributions", *Economics Letters*, 21, 121-126.

Nicolas, F., 1988, "Des normes communes pour les entreprises", Document de la commission des Communautés curopéennes (Office des publications officielles des Communautés curopéennes, Luxembourg).

Novshek, W., 1980, "Equilibrium in simple (or differentiated product) models", *Journal of Economic Theory*, 22, 313-326.

OSBORNE, M.J. AND C., PITCHIK, 1987, "Equilibrium in Hotelling's model of spatial competition", *Econometrica*, 55, 911-922.

PERLOFF, J.M. AND S.C., SALOP, 1985, "Equilibrium with product differentiation", *Review of Economic Studies*, 52, 107-120.

POSNER, R.A., 1976, *Antitrust law: An Economic Perspective*, Chicago: University of Chicago Press.

RAITH, M., 1995, "Product differentiation, uncertainty, and the stability of collusion", Paper presented at the 22nd Annual E.A.R.I.E. Conference, Juan les Pins/Sophia Antipolis, 3-6 September, 1995.

RUBINSTEIN, A., 1982, "Perfect equilibrium in a bargaining model", *Econometrica*, 50, 97-109.

SCHMALENSEE, R., 1982, "Commodity bundling by single-product monopolies", *Journal of Law and Economics*, 25, 67-71.

SCHERER, F.M. AND R., ROSS, 1990, *Industrial Market Structure and Economic Performance*, Boston: Houghton Mifflin.

SCHERER, F.M., 1980, *Industrial Market Structure and Economic Performance*, Chicago: Rand McNally College.

SELTEN, R., 1965, "Spieltheoretische Behandlung eines Oligopol-modells mit Nachfrageträgheit", *Zeitschrift für Gesamte Staatswissenschaft*, 121, 1351-64.

SHAKED, A. AND J., SUTTON, 1982, "Relaxing price competition through product differentiation", *Review of Economic Studies*, 49, 3-13.

SHAKED, A. AND J., SUTTON, 1983, "Natural oligopolies", *Econometrica*, 51, 1469-1483.

SHAKED, A. AND J., SUTTON, 1987, "Product differentiation and industrial structure", *The Journal of Industrial Economics*, 36, 131-146.

SHAPIRO, C. AND D.J., TEECE, 1994, "Systems competition and aftermarkets: an economic analysis of *Kodak*", *The Antitrust Bulletin*, 135-162.

SMITHIES, A., 1941, "Optimum location in spatial competition", *Journal of Political Economy*, 49, 423-439.

SRAFFA, P., 1926, "The laws of returns under competitive conditions", *Economical Journal*, 34, 535-550.

SUTTON, J., 1986, "Vertical product differentiation: Some basic theme", *The American Economic Review*, 393-398.

TABUCHI, AND TAKATOSHI, 1994, "Two-stage two-dimensional spatial competition between two firms", *Regional Science and Urban Economics*, 24, 207-222.

TABUCHI, T. AND J.-F., THISSE, 1995, "Asymmetric equilibria in spatial competition", *International Journal of Industrial Organization*, 13, 213-227.

TIROLE, J., 1988, *The theory of industrial organization*, Cambridge: MIT Press.

QUANDT, R.E. AND W.J., BAUMOL, 1966, "The demand for abstract transport modes: theory and measurement", *Journal Regional Science*, 6, 13-26.

Chapter 2

Vertical product differentiation and outside goods

2.1 Introduction

Consumers differ by their income. This may cause them to choose different product qualities, even if their preferences are the same. Firms recognize the diversity of consumers' tastes caused by income, and differentiate the qualities of their products to capture the consumers. Consequently, the market is segmented between firms and Bertrand competition is avoided.

This economic phenomenon has been observed and formalized by Shaked and Sutton (1982). In their pathbreaking paper, they demonstrate how the existence of quality differences relaxes price competition, so that profits are positive in equilibrium. Quality differences are formalized in a preference framework of Gabszewicz and Thisse (1979). In that framework, individuals with identical preferences may choose different goods because their marginal utilities of income differ.

The formalization of Shaked and Sutton (1982) is usually called vertical product differentiation. The fact that product differentiation relaxes price competition is the focus of their paper. They demonstrate this fact through a three-stage game of entry, quality specification, and price competition. From this game, Shaked and Sutton (1983) derive the so-called "finiteness" property of vertical differentiation which is elaborated further in Sutton (1986).

This formalization of vertical product differentiation has led interests to spread quickly over to many other fields. For example, the issues of cooperative R&D, international trade and investments, and multinational firms with the tariff-jumping problems have been studied by Motta (1992, 1994) using this vertical differentiation framework. Einhorn

(1992) uses it to study compatibility decisions of firms, and more recently, Jeanneret and Verdier (1996) use it to study international competition and protection.

The bulk of this research inspires us to revise the basic model of Shaked and Sutton (1982), and add several missing elements to it. For example, while a subgame perfect equilibrium is used to solve the model, the uniqueness of the equilibrium is not discussed, and most importantly, the degree of product differentiation is not analysed.

These can be done in different ways. One way is to introduce entry. This has been done by Donnenfeld and Weber (1992). They set the quality of the *outside good* equal to zero, and identify the consumers by their income, which is uniformly distributed over an interval $[0, I]$, where I is the upper bound of income. Donnenfeld and Weber show that there exists a unique equilibrium, at which the first two firms enter the industry and select two extremes of the qualities that are technologically feasible. The entrant selects the quality of its product at the middle of the feasible quality interval. Thus, maximal product differentiation exhibits between the two incumbents. This means that the threat of entry increases further the degree of product differentiation.

This chapter is based on Han and Webers (1996). In this chapter, we provide an alternative way through which product differentiation is effected. That is, we consider the effect of outside goods on product differentiation. This effect is explicitly analysed. For this analysis, the duopoly case will be the focus of this chapter. Moreover, entry is blocked given our assumptions of consumers' income.[1] Through an explicit analysis of the subgame perfect equilibria we show that additional insights can be added to the vertical differentiation model of Shaked and Sutton (1982). First, we correct a flaw in Shaked and Sutton's proof of the existence of the subgame perfect equilibrium,[2] by taking also the monopoly case into consideration when the equilibrium prices at the second stage of the game are derived. Second, this correction provides the precondition of the explicit analysis of the effect of outside goods. Based on the main findings of Shaked and Sutton (1982), our analysis shows that a subgame perfect equilibrium not only exists, but is also unique if the range of the technologically feasible quality spectrum is sufficiently small. Otherwise, if the quality spectrum is sufficiently large, multiple equilibria exist which exhibit a certain degree of product differentiation. Finally, we show that in the unique subgame perfect equilibrium case, maximum product differentiation exhibits even in a

[1]As it will become clear later, a sufficiently narrow income range of consumers serves as a barrier to entry.

[2]We argue that a subgame perfect equilibrium derived from the assumption that two firms segment the market as in Shaked and Sutton (1982) may not exist, unless the case is excluded in which a subgame perfect equilibrium of the two-stage game results in a monopoly and creates a higher monopoly profit than any one of the duopoly profits.

model without entrants.

The result shows that for given consumers' income interval, the subgame perfect equilibrium may be unique or multiple depending on the range of the feasible quality spectrum. The result also makes it clear the degree of product differentiation. Particularly, the result illustrates the effect of outside goods on product differentiation, and provides a taxonomy of the degree of vertical product differentiation for a model à la Shaked and Sutton (1982). Thus, the findings of Shaked and Sutton (1982) are improved, where they demonstrate that at any subgame perfect equilibrium one firm chooses the highest available quality while the other firm chooses an available quality somewhere between the two quality extremes.

The intuition is as follows. When the quality spectrum is narrow, the two firms will be squeezed into a restricted product space from which they must make a choice of the product quality. Competition between the two differentiated goods will be so strong that the competition effect from outside goods is strictly dominated and the two firms always try to differentiate their products maximally. On the other hand, when the quality spectrum is large, the two firms will have sufficient room to move in order to make choices of their product qualities. In this case, the competition between the two differentiated goods becomes moderate and a competition effect of outside goods arises. Without cost differences between the two firms one gets the standard result that the lower quality product firm 1 wants more product differentiation, since this relaxes price competition and increases profits (Tirole, 1988). When the competition effect of outside goods arises, firm 1 will face an increased competition. The higher the quality of outside goods, the stronger the competition that firm 1 will face, and the more product differentiation firm 1 wants from firm 2. As our later analysis will show, the degree of product differentiation increases with the competition effect from outside goods, while the prices and profits decrease because of the increased competition.

The remainder of this chapter is organized as follows. The model is described in Section 2.2. In Section 2.3 we give a complete proof of the existence of the unique subgame perfect equilibrium for the quality-then-price game and a taxonomy of the degree of product differentiation in this equilibrium. Section 2.4 concludes. The lengthy proof of the main lemma is given in section 2.5 and the demand functions are specified in the appendix.

2.2 The model

Consider a commodity that can be produced in different quality levels. The technologically feasible level of quality is described by a continuous range, represented by an interval

$Q = [q_m, q_M]$, where q_0 being the quality of outside goods, q_m being the lowest possible quality level, and q_M being the highest feasible quality level. Furthermore, we assume that $0 \leq q_0 < q_m < q_M < +\infty$, with q_0 being the quality of outside goods. We differ from Shaked and Sutton by using a lower bound q_m on the feasible quality interval which is independent of the quality of outside goods, while they use the latter as the lower bound of the quality interval. There are two firms in the industry, a technology follower firm 1 and a technology leader firm 2, each producing a single quality at zero production costs. The firms play a *two-stage game*, first quality, then price, and compete for capturing consumers by offering some packages of price and quality (p_i, q_i), $i \in I = \{1, 2\}$. In the non-generic case $q_1 = q_2$, Bertrand competition results in zero prices and profits for both firms; this is obviously not an interesting case. Therefore, we let $q_1 < q_2$ without loss of generality. Prices are in terms of the outside goods.

A continuum of consumers have identical preference but different income. Consumers distribute uniformly by their income t over the interval $[a, b]$, where $0 < a < b < +\infty$.

A consumer either makes no purchase, or buys exactly one unit of the product from one supplier. If a consumer with income t buys one unit of the commodity from firm $i \in I$ with quality $q_i \in Q$ at price p_i, her utility is given by

$$U(q_i, t - p_i) = q_i(t - p_i),$$

where $t - p_i$ is the consumer's disposable income devoted to the consumption of outside goods, after the purchase of the differentiated good of quality q_i. Each consumer selects a firm by maximizing her utility. If a consumer does not buy, her utility is given by consuming outside goods so that $U(q_0, t) = q_0 t$, where the price of outside goods is normalized to zero. This specification of the consumer's utility function implies that individuals with higher income enjoy quality improvement more than low income consumers. The market area of the product of firm $i \neq j \in I$ at qualities q_i and q_j and at prices p_i and p_j is therefore given by

$$M_i(q_i, q_j, p_i, p_j) = \{t \in [a, b] \mid U(q_i, t - p_i) \geq max\{q_0 t, U(q_j, t - p_j)\}\} \subseteq [a, b],$$

i.e., the set of consumers who prefer to buy from firm i.

At qualities q_i and q_j and at prices p_i and p_j, $i \neq j$, $i \in I$, the demand $D_i(q_i, q_j, p_i, p_j)$ of the commodity of firm $i \in I$ is the integral over all its market areas. For a complete description of the demand functions of firms we refer to the Appendix.

In **Figure** 2.1 we give an interpretation of the market segmentation between firm 1 and firm 2 in case of $t_{01} \leq a$ and $p_2 \leq b$, where $t_{01}, t_{12} \in [a, b]$ denote the *marginal consumer* who is indifferent between buying from outside goods and firm 1, and between buying from firm 1 and firm 2, respectively. **Figure** 2.1 shows that: (a) the lower quality producer firm 1 must always charge a lower price p_1 in order to survive in a market where the higher quality producer firm 2 exists, (b) the market is segmented in such a way that a consumer will buy from firm 1 if her income is lower than t_{12}, and otherwise from firm 2. Thus, firms 1 and 2 capture the market segments of $[a, t_{12}]$ and $[t_{12}, b]$, respectively.

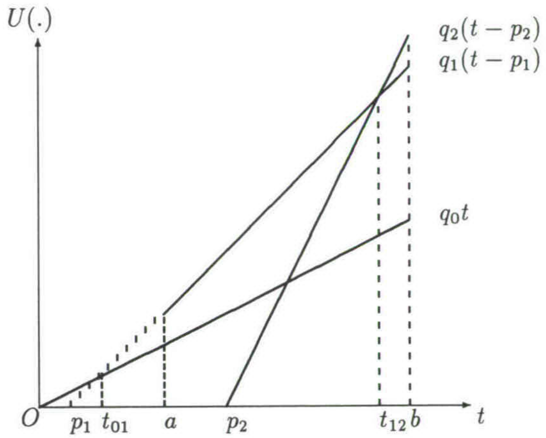


Figure 2.1 Market segmentation for the case $t_{01} \leq a$ and $p_2 \leq b$

The corresponding profits are

$$\pi_i(q_1, q_2, p_1, p_2) = p_i D_i(p_1, p_2, q_1, q_2), \text{ for firm } i \in I.$$

2.3 Quality and price competition

Consider the following two-stage game, in which a technology leader firm 2 and a technology follower firm 1 compete first on quality specifications of their products and then on pricing. From Shaked and Sutton (1982) we know that for n firms offering distinct qualities of products, if the income distribution interval $[a, b]$ satisfies the condition $2a < b < 4a$, then exactly two firms will have positive market shares at the price equilibrium. Moreover, at equilibrium the market is covered, i.e., no consumer stays out of the market. Since we analyse the duopoly case, we adopt the assumption that $2a < b < 4a$.

In this section, we extend Shaked and Sutton's discussion to prove for the duopoly case that under the assumption of $2a < b < 4a$, there is a unique subgame perfect equilibrium, at which both firms maximally differentiate their products if the given quality spectrum is sufficiently narrow. Otherwise, if the quality spectrum is sufficiently large, there exist multiple equilibria in which some degree of product differentiation arises.

First, we want to show that at such a market consumers can not be monopolized. That is, neither the technology leader firm 2 nor the technology follower firm 1 is able to monopolize the given market by excluding its rival.

Lemma 2.3.1 *For any given quality specifications q_1 of firm 1 and q_2 of firm 2, with $q_1, q_2 \in Q$ and $q_1 < q_2$, neither of the two firms can force the other firm to stay out of the market through price competition.*

Proof. See Section 5.

□

This lemma shows that the market is always segmented between firm 1 and firm 2 given our conditions on the income spectrum. **Figure** 2.1 shows that a consumer whose income is lower than t_{12} will purchase from firm 1 and otherwise from firm 2. This provides a necessary condition to analyse the effect of outside goods on product differentiation explicitly. We are therefore in a position to discuss the subgame perfect equilibrium of the two-stage game in order to provide a taxonomy of the product differentiation between the duopoly. For the subsequent analysis, we shall make use of the marginal consumer definition and distinguish between the cases $q_0 = 0$ and $q_0 > 0$.

2.3.1 The case $q_0 = 0$

In this case, the condition on marginal consumer leads directly to the following equations

$$q_1(t_{01} - p_1) = 0$$

and

$$q_2(t_{12} - p_2) = q_1(t_{12} - p_1),$$

where t_{01} and t_{12} represent the consumers who are indifferent between staying out of the market and buying from firm 1, and buying from firm 1 and firm 2, respectively. Thus, it follows that

$$t_{01} = p_1$$

and

$$t_{12} = (p_2 q_2 - p_1 q_1)/(q_2 - q_1). \tag{2.3.1}$$

Because of Lemma 1 and given the assumption that the firms' production costs are zero, the duopolists' profits can be written as

$$\pi_1 = \begin{cases} p_1(t_{12} - a) & t_{01} \leq a \\ p_1(t_{12} - t_{01}) & t_{01} > a, \end{cases}$$

$$\pi_2 = p_2(b - t_{12}).$$

At this stage we are in a position to apply the finding of Shaked and Sutton (1982). That is, given that two firms compete at both stages and that the income range of consumers satisfies the condition $2a < b < 4b$, entry is blocked, the vertically differentiated market holds exactly two firms, and all consumers buy from one of these firms. Therefore, the firms' profits can be rewritten as

$$\pi_1 = p_1(t_{12} - a), \text{ with } p_1 = t_{01} \leq a \tag{2.3.2}$$

and

$$\pi_2 = p_2(b - t_{12}). \tag{2.3.3}$$

Substituting (2.3.1) for t_{12} in (2.3.2) and (2.3.3) we calculate directly the Nash equilibrium prices and the associated profits of firms 1 and 2 as

$$p_1^n = \frac{q_2 - q_1}{3q_1}(b - 2a), \text{ with } p_1^n = t_{01} \leq a, \text{ and } p_2^n = \frac{q_2 - q_1}{3q_2}(2b - a);$$
$$\pi_1^n = \frac{q_2 - q_1}{9q_1}(b - 2a)^2, \text{ and } \pi_2^n = \frac{q_2 - q_1}{9q_2}(2b - a)^2.$$

Let $\alpha = q_1/q_2$ denote the degree of product differentiation and $\underline{\alpha} = q_m/q_M$ denote the maximum product differentiation. Then, $\underline{\alpha} \leq \alpha \leq 1$ and the lower the $\underline{\alpha}$, the larger the feasible product quality spectrum. The Nash equilibrium prices and the reduced profit function forms of the firms can thus be written as

$$p_1^n = \frac{1 - \alpha}{3\alpha}(b - 2a), \text{ with } p_1^n = t_{01} \leq a, \text{ and } p_2^n = \frac{1 - \alpha}{3}(2b - a); \tag{2.3.4}$$
$$\pi_1^n = \frac{1 - \alpha}{9\alpha}(b - 2a)^2, \text{ and } \pi_2^n = \frac{1 - \alpha}{9}(2b - a)^2. \tag{2.3.5}$$

Differentiating the reduced profit function forms of both firms we have that $\partial\pi_1^n(\alpha)/\partial\alpha < 0$ and $\partial\pi_2^n(\alpha)/\partial\alpha < 0$. Therefore, the two firms will differentiate their products as largely as possible at the first stage of quality competition in order to maximize their respective profits. That is, the two firms prefer to keep α as small as possible. Considering that this differentiation is restricted by $t_{01} = p_1^n \leq a$, however, we have $\alpha \geq \frac{b-2a}{a+b}$. Therefore, potentially the two firms would prefer to keep the degree of their product differentiation at $\frac{b-2a}{a+b}$. Let α^{nn} denote the degree of product differentiation at equilibria, we then have $\alpha^{nn} = max\{\underline{\alpha}, \frac{b-2a}{a+b}\}$. The following proposition then follows.

Proposition 2.3.1 *Suppose that two firms compete first on qualities and then on prices. Then, (i) if $\underline{\alpha} \geq \frac{b-2a}{a+b}$, there exists a unique subgame perfect equilibrium in pure strategies which exhibits maximum product differentiation, and the equilibrium prices and profits are*

$$p_1^{nn} = \frac{1 - \underline{\alpha}}{3\underline{\alpha}}(b - 2a), \textit{ and } p_2^{nn} = \frac{1 - \underline{\alpha}}{3}(2b - a);$$
$$\pi_1^{nn} = \frac{1 - \underline{\alpha}}{9\underline{\alpha}}(b - 2a)^2, \textit{ and } \pi_2^{nn} = \frac{1 - \underline{\alpha}}{9}(2b - a)^2.$$

(ii) Otherwise, there exist subgame perfect equilibria in pure strategies which exhibit product differentiation at the degree of $\frac{b-2a}{a+b}$. *The equilibrium prices and profits are*

$$p_1^{nn} = a, \text{ and } p_2^{nn} = \frac{a(2b-a)}{a+b};$$
$$\pi_1^{nn} = \frac{a(b-2a)}{3}, \text{ and } \pi_2^{nn} = \frac{a(2b-a)^2}{3(a+b)},$$

where nn denotes the competition at both stages.

Proof. We are only left to prove that the consequent equilibrium prices and profits hold. Substituting $\underline{\alpha}$ and $\frac{b-2a}{a+b}$ for α in (2.3.4)-(2.3.5) in the cases (i) and (ii), respectively, leads directly to the equilibrium prices and profits.

□

This proposition shows that competition on first qualities and then prices leads the two firms to potentially differentiate their products at a degree of $\frac{b-2a}{a+b}$. Because this potential degree of product differentiation is constrained by the range of the feasible quality spectrum, the two firms will then differentiate their products maximally if this potential degree of product differentiation is larger than the range of the feasible quality spectrum. Otherwise, the potential degree of product differentiation will become the real degree of product differentiation exhibited between the two firms. In the former case, the equilibrium is unique, and the quality leader and follower choose the highest and the lowest product qualities, respectively. In the latter case, however, any choice of product qualities which exhibits a degree of product differentiation at $\frac{b-2a}{a+b}$ will be an equilibrium.

2.3.2 The case $q_0 > 0$

Similarly, in this case the condition on the marginal consumer leads directly to the equations

$$q_1(t_{01} - p_1) = q_0 t_{01}$$

and

$$q_2(t_{12} - p_2) = q_1(t_{12} - p_1).$$

Thus, it follows that

$$t_{01} = \frac{q_1 p_1}{q_1 - q_0}$$

and

$$t_{12} = \frac{p_2 q_2 - p_1 q_1}{q_2 - q_1}. \tag{2.3.6}$$

Repeating the arguments similar to that of the case $q_0 = 0$ yields the two firms' profits as

$$\pi_1 = p_1(t_{12} - a), \text{ with } t_{01} = \frac{p_1 q_1}{q_1 - q_0} \leq a \tag{2.3.7}$$

and

$$\pi_2 = p_2(b - t_{12}). \tag{2.3.8}$$

Substituting (2.3.6) for t_{12} in (2.3.7) and (2.3.8) and then applying the first order condition yield the equilibrium prices and the associated profits of the two firms as

$$p_1^N = \frac{b-2a}{3}\frac{q_2 - q_1}{q_1}, \text{ with } \tfrac{q_2-q_0}{q_2-q_1} \geq \tfrac{b+a}{3a}, \text{ and } p_2^N = \frac{2b-a}{3}\frac{q_2-q_1}{q_2}; \tag{2.3.9}$$

$$\pi_1^N(q_1, q_2) = \frac{(b-2a)^2}{9}\frac{q_2-q_1}{q_1}, \text{ and } \pi_2^N(q_1, q_2) = \frac{(2b-a)^2}{9}\frac{q_2-q_1}{q_2}. \tag{2.3.10}$$

Differentiating the reduced profit function forms of both firms yields $\partial\pi_1^N(q_1, q_2)/\partial q_1 < 0$ and $\partial\pi_2^N(q_1, q_2)/\partial q_2 > 0$. Therefore, the two firms will differentiate their products as largely as possible at the first stage of quality competition in order to maximize their respective profits. In other words, the two firms prefer to keep α as small as possible. Considering that this differentiation is restricted by $\frac{q_2-q_0}{q_2-q_1} \geq \frac{b+a}{3a}$, however, we have $\alpha \geq \frac{b-2a}{b+(1-2\frac{q_0}{q_m})a}$. Therefore, the two firms would potentially differentiate their products at a degree of $\frac{b-2a}{b+(1-2\frac{q_0}{q_m})a}$. Let α_1^{nn} denote the degree of product differentiation at equilibria, we then have $\alpha_1^{nn} = max\{\underline{\alpha}, \frac{b-2a}{b+(1-2\frac{q_0}{q_m})a}\}$. Summarizing, we have the following proposition.

Proposition 2.3.2 *Suppose that two firms compete first on qualities and then on prices. Then, (i) if* $\underline{\alpha} \geq \frac{b-2a}{b+(1-2\frac{q_0}{q_m})a}$, *there exists a unique subgame perfect equilibrium in pure strategies which exhibits maximum product differentiation, and the equilibrium prices and profits are*

$$p_1^{nn} = \frac{1-\underline{\alpha}}{3\underline{\alpha}}(b-2a), \text{ and } p_2^{nn} = \frac{1-\underline{\alpha}}{3}(2b-a);$$
$$\pi_1^{nn} = \frac{1-\underline{\alpha}}{9\underline{\alpha}}(b-2a)^2, \text{ and } \pi_2^{nn} = \frac{1-\underline{\alpha}}{9}(2b-a)^2.$$

(ii) Otherwise, there exist subgame perfect equilibria in pure strategies which exhibit product differentiation at the degree of $\frac{b-2a}{b+(1-2\frac{q_0}{q_m})a}$. *The equilibrium prices and profits are*

$$p_1^{nn} = a, \text{ and } \pi_1^{nn} = \frac{a(b-2a)}{9}(3-2\frac{q_0}{q_m});$$
$$p_2^{nn} = \frac{a(2b-a)}{3}\frac{3-2\frac{q_0}{q_m}}{b+a(1-2\frac{q_0}{q_m})}, \text{ and } \pi_2^{nn} = \frac{a(2b-a)^2}{9}\frac{3-2\frac{q_0}{q_m}}{b+a(1-2\frac{q_0}{q_m})},$$

where nn denotes the competition at both stages.

Proof. We are only left to prove that the consequent equilibrium prices and profits hold. Substituting $\underline{\alpha}$, and $\frac{b-2a}{b+a(1-2\frac{q_0}{q_m})}$ for α in (2.3.9) -(2.3.10) in the cases (i), and (ii), respectively, leads directly to the equilibrium prices and profits.

□

This proposition shows that competition on first qualities and then prices leads the two firms to potentially differentiate their products at a degree of $\frac{b-2a}{b+(1-2\frac{q_0}{q_m})a}$. Because this potential degree of product differentiation is constrained by the range of the feasible quality spectrum, the two firms will differentiate their products maximally if this potential degree of product differentiation is larger than the range of the feasible quality spectrum. Otherwise, the potential degree of product differentiation will become the real degree of product differentiation exhibited between the two firms. In the former case, the equilibrium is unique, and the quality leader and follower choose the highest and lowest product qualities, respectively. In the latter case, however, any choice of product qualities which exhibits a degree of product differentiation at $\frac{b-2a}{b+(1-2\frac{q_0}{q_m})a}$ will be an equilibrium.

At this stage, the effect of outside goods on product differentiation can be clearly observed through comparing Propositions 1 and 2 (see also **Figure** 2.5 of Section 5). Potentially, the two firms prefer to differentiate their products at a degree of $\frac{b-2a}{b+(1-2\frac{q_0}{q_m})a}$ when the competition from outside goods is taken into account. Given the fact that $0 \leq q_0 < q_m$, this degree of product differentiation lies between the lower bound of $\frac{b-2a}{a+b}$ and the upper bound of $\frac{b-2a}{b-a}$.

When the feasible quality spectrum is sufficiently small, the two firms will be squeezed into a limited production space to make a choice of the product quality. Then, competition between the differentiated goods will be so strong that competition effect from outside goods is strictly dominated and the two firms always try to differentiate their products maximally. Otherwise, when the feasible quality spectrum is sufficiently large, the two firms will have sufficiently large room to move in order to make choices of their product qualities. In this case, competition between the differentiated goods becomes moderate and competition effect of outside goods arises. Without any cost differences between the two firms, one would find the standard result that the lower quality product firm 1 wants more product differentiation, since this relaxes price competition and increases profits (Tirole, 1988). When competition effect of outside goods arises, the competition faced by firm 1 is increased. The higher the quality of outside goods, the stronger the competition that firm 1 will face, and the more product differentiation that firm 1 wants from firm 2. At its lower extreme, when the quality of outside goods is zero, the two firms will differentiate their products at the lower bound of the degree of product differentiation, which is $\frac{b-2a}{a+b}$. When the quality of outside goods increases or the competition effect of outside goods becomes stronger, the degree of product differentiation is also increased. At its upper extreme, when q_0 goes to q_m the two firms will reach the highest degree of product differentiation which is $\frac{b-2a}{b-a}$. Direct comparison of the equilibrium levels of prices and profits shows, however, that although the degree of product differentiation is increased along with the increased competition effect from outside goods, the equilibrium levels of prices and profits of the two firms are decreased because of the increased competition.

2.4 Conclusions

We have extended Shaked and Sutton's (1982) analysis in this chapter and provided an taxonomy of the degree of product differentiation when the competition effect of outside goods is taken into account. In order to extend Shaked and Sutton's discussion and examine the competition effect of outside goods, a precondition that the concerned market can not be monopolized must be provided. Due to the fact that this precondition holds, the effect of outside goods on product differentiation can be discussed explicitly.

The analysis shows that when the feasible quality spectrum is sufficiently narrow, the two firms will be squeezed into a limited production space to make a choice of the product quality. Then, competition between the differentiated goods will be so strong that the competition effect of outside goods is strictly dominated and the two firms always try to differentiate their products maximally. Therefore, in this case the effect of outside goods can not be clearly observed. Otherwise, when the feasible quality spectrum is sufficiently large, the two firms will have sufficiently large room to move in order to make choices of their product qualities. Then, competition between the differentiated goods becomes moderate and the competition effect of outside goods arises and is clearly observed: The higher the quality of outside goods, the stronger the competition that firm 1 will face, and the more product differentiation that firm 1 then wants from firm 2. In general, the degree of product differentiation lies in the range of $[\frac{b-2a}{a+b}, \frac{b-2a}{b-a}]$ given that the quality of outside goods lies between zero and the lower bound of the feasible quality spectrum. Moreover, although the degree of product differentiation is increased when the competition effect of outside goods is increased, the equilibrium levels of prices and profits of the two firms are decreased because of the increased competition.

Thus far, an alternative way through which product differentiation is effected has been discussed. It is found that, in general, the increased competition from outside goods increases the degree of product differentiation. Since Shaked and Sutton (1982) discover that the important concern of product differentiation is to relax price competition, one of the interests of successors has been to study factors that effect product differentiation (see de Palma et al. (1985), Shaked and Sutton (1987), and Freedman and Thisse (1993)). These studies have important implications to the industrial market structure. In the next chapter, we will fix the quality of outside goods, and turn to study other factors. More precisely, the effect of different combinations of business strategies, such as prices and qualities, on product differentiation will be examined.

2.5 Proofs

Proof of Lemma 2.3.1

Suppose that a Nash-Bertrand equilibrium at the second stage of the game exists for given q_1 and q_2, and we denote it by (p_1^N, p_2^N). We prove that (p_1^N, p_2^N) can not happen at the case where one of the two firms stays out of the market.

It is straightforward to prove that firm 2 can not stay out of the market at (p_1^N, p_2^N), because firm 2 can always set a price $p_2^{'} = p_1^N$ and take over the market from firm 1 or at worst share the market with firm 1. Next we need to prove that firm 1 can not stay out of the market at (p_1^N, p_2^N), for which we follow a graphical proof and distinct between three cases:

<u>case 1</u>: $p_2^N < p_1^N$. Then $D_1(q_1, q_2, p_1^N, p_2^N) = 0$, and so $\pi_1(q_1, q_2, p_1^N, p_2^N) = 0$.

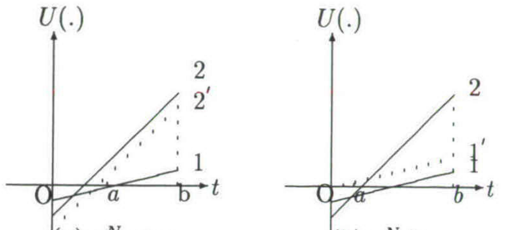
From (a) of **Figure** 2.2, it is found that if $p_2^N < a$, then firm 2 has an incentive to deviate from p_2^N, because by charging an infinitesimal higher price, its demand is not affected, and consequently its profit is increased. Similarly from (c) of **Figure** 2.2, it is found that if $p_2^N \geq a$, then firm 1 has an incentive to deviate from p_1^N by setting its price at $p_1^{'}$ with $0 < p_1^{'} < a$, because then firm 1 gains a positive market share.

<u>case 2:</u> $p_2^N = p_1^N$. Then $D_1(q_1, q_2, p_1^N, p_2^N) = 0$, and so $\pi_1(q_1, q_2, p_1^N, p_2^N) = 0$.

From (a) of **Figure** 2.3 it is found that if $p_2^N \geq a$, then firm 1 has an incentive to deviate by setting its price at $p_1^{'}$ with $0 < p_1^{'} < a$, because then firm 1 gains a positive market share. Similarly from (b) of **Figure** 2.3, it is found that if $p_2^N < a$, firm 2 has an incentive to deviate, because by charging an infinitesimal higher price, its demand is not affected, and consequently its profit is increased.

<u>case 3:</u> $p_2^N > p_1^N$. Then firm 1 stays out of the market if and only if $t_{12} \leq a$, and so $\pi_1(q_1, q_2, p_1^N, p_2^N) = 0$.

From (a) of **Figure** 2.4 it is found that if $t_{12} < a$, then firm 2 has an incentive to deviate, because by charging an infinitesimal higher price, its demand is not affected, and consequently its profit is increased. If $t_{12} = a$ and $p_1^N > 0$, then firm 1 has an incentive to deviate, because then firm 1 gains a positive market share, so a positive profit. Otherwise if $t_{12} = a$ but $p_1^N = 0$, then firm 2 has an incentive to deviate. In fact, if firm 2 does not deviate, its profit π^{nd} is given by $\pi^{nd} = p_2^N(b - t_{12})$, where $t_{12} = a$ satisfies the equation $q_1(t_{12} - 0) = q_2(t_{12} - p_2^N)$. Solving the equation for p_2^N and then substituting p_2^N and t_{12} into the equation for π^{nd}, we derive the profit $\pi^{nd} = a(b-a)(q_2 - q_1)/q_2$ for firm 2 in case it does not deviate. But if firm 2 deviates by maximizing its profit $p_2(b - t_{12}^{'})$, where $t_{12}^{'}$ is given by the equation $q_1(t_{12}^{'} - 0) = q_2(t_{12}^{'} - p_2)$, then its profit π^d equals $\pi^d = b^2(q_2 - q_1)/(4q_2)$. For $2a < b$, we have $\pi^d > \pi^{nd}$, so firm 2 has an incentive to deviate.

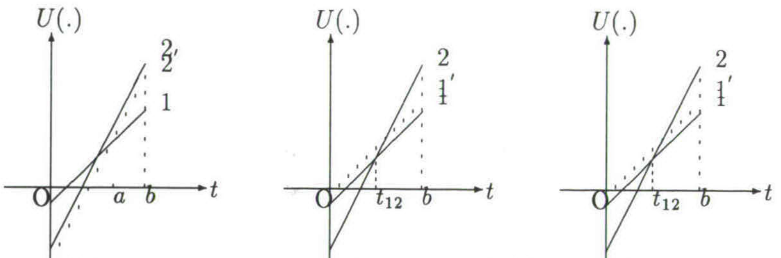


(a) $p_2^N < a$ (b) $p_2^N \geq a$

Figure 2.2 $p_2^N < p_1^N$

(a) $p_2^N \geq a$ (b) $p_2^N < a$

Figure 2.3 $p_2^N = p_1^N$



(a) $t_{12} < a$ (b) $t_{12} = a$ and $p_1^N > 0$ (c) $t_{12} = a$ and $p_1^N = 0$

Figure 2.4 $p_2^N > p_1^N$

□

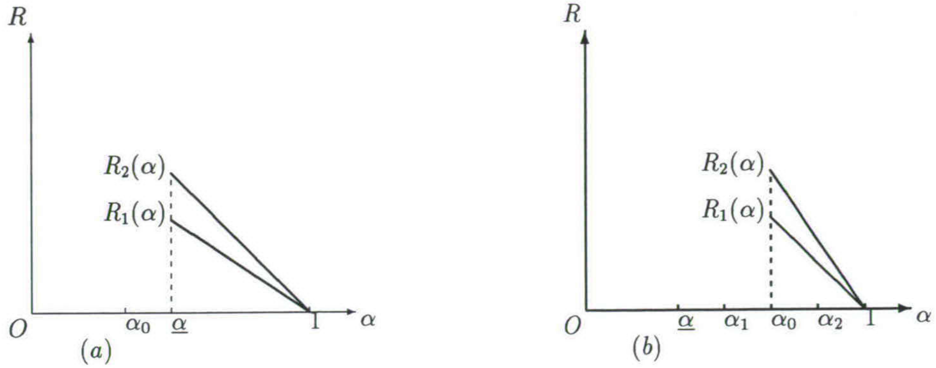


Figure 2.5 $\alpha_0 = \frac{b-2a}{b+(1-2\frac{q_0}{q_m})a}, \alpha_1 = \frac{b-2a}{b+a}, \alpha_2 = \frac{b-2a}{b-a}, \underline{\alpha} = \frac{q_m}{q_M}$.

Appendix

The demand functions of Firm 1 and Firm 2

We may distinguish three different types of indifferent consumers, namely a consumer being indifferent between buying from firm 1 and not buying at all, a consumer being indifferent between buying from firm 2 and not buying at all, and, finally, a consumer being indifferent between buying from firm 1 and buying from firm 2. We denote $t_{12} = \frac{p_2 q_2 - p_1 q_1}{q_2 - q_1}$ and $t_{0i} = (\frac{q_i}{q_i - q_0})p_i$ for all $i \in I = \{1, 2\}$.

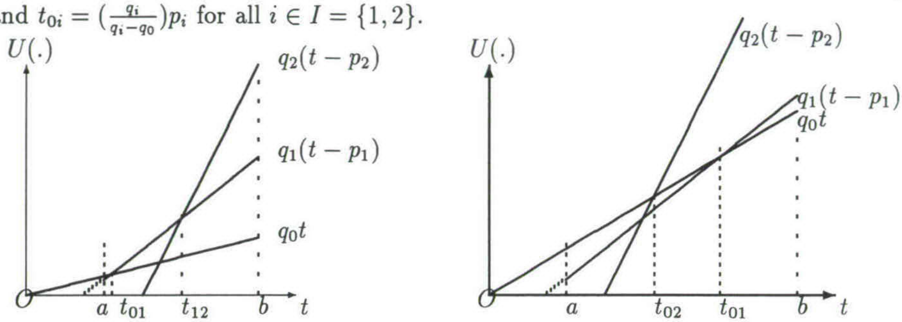


Figure 2.6 (a) $p_1 \leq a \leq p_2$, q_0 small **Figure** 2.6 (b) $p_1 \leq a \leq p_2$, q_0 large

If q_0 is relatively small, as in **Figure** 2.6(a), there exists a consumer t_{01} being indifferent between buying from firm 1 and not buying if $t_{01} \geq a$, otherwise all consumers prefer to buy. Furthermore, there exists a consumer t_{12} being indifferent between buying from firm 1 and firm 2 if $a \leq t_{12} \leq b$.

If q_0 is relatively high, as in **Figure** 2.6(b), there does not exist a consumer t_{12} being indifferent between buying from firm 1 and buying from firm 2. The reason is that all consumers prefer the outside option or the commodity of firm 2 to the commodity of firm 1. Clearly, there does not exist a consumer t_{02} being indifferent between buying from firm 2 and not buying if $t_{02} \geq b$.

Consequently, the demand for the firms can be written as

$$D_1(q_1, q_2, p_1, p_2) = 0, \text{ for } p_1 \geq p_2,$$

$$\text{and } D_1(q_1, q_2, p_1, p_2) = \begin{cases} t_{12} - t_{01} & \text{if } a \leq t_{01} \leq t_{12} \leq b \\ t_{12} - a & \text{if } t_{01} \leq a \leq t_{12} \leq b \\ b - t_{01} & \text{if } a \leq t_{01} \leq b \leq t_{12} \\ b - a & \text{if } t_{01} \leq a, b \leq t_{12} \\ 0 & \text{otherwise,} \end{cases} \quad \text{for } p_1 < p_2$$

and

$$D_2(q_1, q_2, p_1, p_2) = \begin{cases} b - a & \text{if } a \geq t_{02} \\ b - t_{12} & \text{if } a \leq t_{02} \leq b \quad \text{for } p_1 \geq p_2 \\ 0 & \text{otherwise,} \end{cases}$$

and

$$D_2(q_1, q_2, p_1, p_2) = \begin{cases} b - a & \text{if } a \geq max\{t_{01}, t_{12}\} \\ b - max\{t_{02}, t_{12}\} & \text{if } a \leq t_{12} \leq b \qquad\qquad \text{for } \; p_1 < p_2. \\ 0 & \text{otherwise.} \end{cases}$$

References

DE PALMA, A., V., GINSBURGH, AND Y.Y., PAPAGEORGIOU, 1985, "The Principle of Minimum Product Differentiation Holds under Sufficient Heterogeneity", *Econometrica*, 53, 767-781.

DONNENFELD, S. AND S., WEBER, 1992, "Vertical Product Differentiation with Entry", *International Journal of Industrial Organization*, 10, 449-472.

EINHORN, M.A., 1992, "Mix and match compatibility with Vertical Product dimensions", *Rand Journal of Economics*, 23, 535-546.

FRIEDMAN, J.W. AND J.-F., THISSE, 1993, "Partial Collusion Fosters Minimum Product Differentiation", *RAND Journal of Economics*, 24, 631-645.

GABSZEWICZ, J. AND J.-F., THISSE, 1979, "Price Competition, Quality and Income Disparities", *Journal of Economic Theory*, 20, 340-359.

JEANNERET, M.-H. AND T., VERDIER, 1996, "Standardization and protection in a vertical differentiation model", *European Journal of Political Economy*, 12, 253-271.

HAN, X. AND H., WEBERS, 1996, "A comment on Shaked and Sutton's model of vertical product differentiation", CentER Discussion paper, No. 9666, Tilburg University.

MOTTA, M., 1992, "Cooperative R&*D* and vertical product differentiation", *International Journal of Industrial Organization*, 10, 643-661.

MOTTA, M., 1992, "Multinational firms and the tariff-jumping argument - A game theoretic analysis with some unconventional conclusions", *European Economic Review*, 36, 1557-1571.

MOTTA, M., 1994, "International trade and investments in a vertically differentiated industry", *International Journal of Industrial Organization*, 12, 179-196.

SHAKED, A. AND J., SUTTON, 1982, "Relaxing Price Competition Through Product Differentiation", *Review of Economic Studies*, 49, 3-13.

SHAKED, A. AND J., SUTTON, 1983, "Natural Oligopolies", *Econometrica*, 51, 1469-1483.

SHAKED, A. AND J., SUTTON, 1987, "Product Differentiation and Industrial Structure", *The Journal of Industrial Economics*, 36, 131-146.

SUTTON, J., 1986, "Vertical Product Differentiation: Some Basic Theme", *The American Economic Review*, 76, 393-398.

TIROLE, J., 1988, *The theory of industrial organization*, The MIT Press, Cambridge, MA.

Chapter 3

Competition and cooperation in a vertically differentiated duopoly

3.1 Introduction

In a competitive market, firms have generally a package of business strategies, such as prices, qualities or R&D investments, and quantities, etc, to manipulate. Thus in principle, firms may collude in some aspects of the interaction and compete in other aspects. We refer to such behaviour as semicollusion.

In this chapter, we consider the case where firms try to manipulate both qualities and prices. Because quality improvements involve sunk costs (like R&D investments), product quality is a less flexible variable, and once chosen, will be fixed for a certain period. This inflexibility of the product quality choice makes it difficult to reach an agreement between firms since the binding force is absent and may lead firms to compete in product quality specifications. Prices, however, are flexible and may be changed overnight. Therefore, firms may meet each other many times in a certain period. This flexibility of price choices creates frequent price competition. As a result, firms may lobby for collusive pricing because a binding force to punish the deviators may be created by repeated price competition. Conventional wisdom indeed suggests that firms in oligopolistic markets are better off colluding rather than competing on prices.[1] One classic example of this semicollusion is provided in Scherer (1992, p.250-1). In the American cigarette industry of the 1920s and 1930s, the Big Three (American, Ligget Myers, and Reynolds) controlled between 70% and 90% of the market during the period and there is evidence that they cooperated on prices while competing in product quality controls.

[1]See Tirole (1988, ch. 6) and the surveys by Jacquemin and Slade (1989) and Shapiro (1989) in the *Handbook of Industrial Organization*.

Nevertheless, the possibility exists for firms to cooperate in R&D in order to achieve a common adopted quality. In this case, however, it seems reasonable to extend the cooperation to the price stage to have full cooperation. The idea is to allow partners who have achieved inventions together, also to control together their product pricing which embodies the results of their collaboration, in order to recuperate jointly their R & D investments.

Hence, three cases arise when firms try to manipulate qualities and prices: (a) cooperation on both qualities and prices, (b) noncooperation on qualities but cooperation on prices, (c) noncooperation on both qualities and prices. The consequences of these business strategies and their effects on the degree of product differentiation emerge then for analysis.

Several papers have addressed the semicollusion in which the second stage is collusive. Jehiel (1992) and Friedman and Thisse (1993) consider a variant of Hotelling's (1929) *spatial competition* model in which two firms choose product locations non-cooperatively and then collude on prices through playing trigger strategies. They show that the location choices of firms involve a pairing of firms at the market center, that is, the Hotelling's principle of minimum product differentiation is restored by this semicollusion.

Matsui (1989) and Sevy (1992) consider similar settings but are interested in the effects of semicollusion on consumer surplus. Matsui considers a model in which firms choose capacity at the first stage and quantities at the second stage. He shows that consumer surplus may increase if firms cooperate rather than compete at the second stage. Sevy considers a model in which firms invest in R & D at the first stage and choose prices at the second stage. He shows that consumer surplus may increase when the firm of lower production cost is granted a monopoly at the second stage.

Osborne and Pitchik (1987), Davidson and Deneckere (1990), and Fershtman and Gandal (1994) consider similar settings but investigate profits of semicollusion. They show that when firms invest in product capacity at the first stage and then choose prices at the second stage semicollusion leads, in general, to excess capacity, higher prices and lower profits than noncooperation.

To the best of our knowledge, however, semicollusive equilibrium behaviour of firms in a vertically differentiated market has not been analysed yet. In the relevant vertical differentiation settings of Shaked and Sutton (1982) and Gabszewicz and Thisse (1986) a two-stage game of, first, quality, then, price is played non-cooperatively between firms. It is shown that product differentiation relaxes price competition. Donnefeld and Weber (1992) show in a similar setting that further differentiation to the maximum is exhibited between a duopoly if entry is allowed.

We study vertical product differentiation in this chapter and are interested in the business strategies that firms will choose if a package of business strategies such as quality and price are available. Furthermore, we are interested in the effect of the cooperation and noncooperation choices of firms on the degree of product differentiation. The latter is a central proposition considered by successors of Hotelling's (1929) model.

A vertically differentiated duopoly is studied in this chapter and the main results of this study are as follows: (a) Two firms will cooperate on both qualities and prices and differentiate their products maximally; the product quality follower charges a price higher than the full competition price, but lower than the semicollusion price; the product quality leader, however, charges a price higher than both the full competition price and the semicollusion price; (b) Competition on both qualities and prices leads the two firms to differentiate their products at a degree which depends on the range of the income distribution of consumers; (c) Semicollusion leads the two firms to differentiate their products either minimally in a partially covered market where both firms choose the highest feasible product quality, or at any degree in an entirely covered market where the product quality leader chooses the highest feasible product quality. The first is in sharp contrast with a model[2] *à la* Hotelling (1929), in which two firms differentiate their products at some degree and locate at one quarter and three quarters of a unit interval, respectively, if they cooperate at both stages. The last is parallel to Friedman and Thisse (1993) in which semicollusion fosters minimum product differentiation. While in their case two firms agglomerate at the market center, in our case both firms choose the highest feasible product quality.

The remainder of this chapter is organized as follows. In Section 2 we present the model while equilibria are derived in Section 3. Comparative statics follows in Section 4 to derive our main conclusions of this chapter. We conclude this chapter in Section 5 with a brief summary.

3.2 The model

The model is a modified variant of Shaked and Sutton (1982), and similar to that of Chapter 2. Suppose some good may be produced in a continuous range of quality levels, represented by a technologically feasible quality interval $Q = [q_m, q_M]$, where $0 \leq q_0 < q_m < q_M < +\infty$, q_0 being the quality of the outside good, q_m being the lowest feasible quality level, and q_M being the highest feasible quality level. Without loss of generality of the comparative statistics we assume $q_0 = 0$ in this chapter. We differ from Shaked and

[2]See Gabszewicz and Thisse (1979), for example.

Sutton by using a lower bound q_m on the feasible quality interval that is independent of the quality of the outside good, while they use the latter as the lower bound on the quality interval. There are two firms in the industry, a technology follower firm 1 and a technology leader firm 2, each producing a single quality at zero costs. The firms play a two-stage game, first qualities, then prices, and compete for consumers by offering packages of price and quality (p_i, q_i), $i \in I = \{1, 2\}$. In the non-generic case $q_1 = q_2$, Bertrand competition results in zero prices and zero profits for both firms; this is obviously not an interesting case. Therefore, we let $q_1 < q_2$ without loss of generality. Prices are in terms of the numeraire good.

A continuum of consumers have identical preferences but different incomes. Income t is uniformly distributed over the interval $[a, b]$ where $0 < a < b < +\infty$.

Consumers make indivisible and mutually exclusive purchases from the quality interval Q, in the sense that a consumer either makes no purchase, or buys exactly one unit of the product from either suppliers. If a consumer with income t buys one unit of the commodity from firm $i \in I$ with quality $q_i \in Q$ at price p_i, his utility is given by

$$U(q_i, t - p_i) = q_i(t - p_i),$$

where $t - p_i$ is the consumer's disposable income devoted to the consumption of the numeraire good after the purchase of the differentiated good of quality q_i. Each consumer selects a firm by maximizing her utility. If a consumer does not buy, her utility is given by consuming the outside good only so that $U(t, q_0, 0) = q_0 t$ (zero in this chapter). This specification of the utility functions of consumers implies that individuals with higher incomes enjoy quality improvements more than low income consumers. The market area of the product of firm $i \neq j \in I$ at qualities q_i and q_j and at prices p_i and p_j is therefore given by

$$M_i(q_i, q_j, p_i, p_j) = \{t \in [a, b] \mid U(t, q_i, p_i) \geq max\{0, U(t, q_j, p_j)\}\},$$

i.e., the set of consumers that prefer to buy from firm i.

At qualities q_i and q_j and at prices p_i and p_j, $i \neq j$, $i \in I$, the demand $D_i(q_i, q_j, p_i, p_j)$ for the commodity of firm $i \in I$ is equal to

$$D_i(q_i, q_j, p_i, p_j) = \int_{M_i(q_i, q_j, p_i, p_j)} dt.$$

In **Figure** 3.1 we give an interpretation of the market segmentation between firm 1 and firm 2 in case $p_1 \leq a$ and $p_2 \leq b$, where $t_{12} \in [a, b]$ denotes the marginal consumer who is indifferent between buying from firm 1 and buying from firm 2. **Figure** 3.1 shows that: (a) the lower quality producer firm 1 must always charge a lower price p_1 in order to survive in a market where the higher quality producer firm 2 exists, (b) the market is segmented in such a way that a consumer will buy from firm 1 if his income is lower than t_{12}, and otherwise from firm 2. Thus, firms 1 and 2 capture the market segments of $[a, t_{12}]$ and $[t_{12}, b]$ respectively. For a complete description of the demand functions of the firms we refer to the Appendix of Chapter 2.

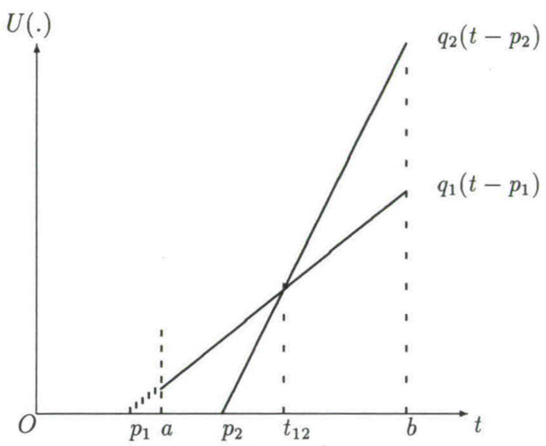


Figure 3.1 Market segmentation for the case $p_1 \leq a$ and $p_2 \leq b$

From the condition on the marginal consumers we have

$$q_1(t_{01} - p_1) = 0$$

and

$$q_2(t_{12} - p_2) = q_1(t_{12} - p_1),$$

where t_{01} represents the marginal consumer who is indifferent between not buying and buying from firm 1. Thus, it follows that

$$t_{01} = p_1$$

and

$$t_{12} = (p_2 q_2 - p_1 q_1)/(q_2 - q_1). \tag{3.2.1}$$

Assuming zero costs we derive the profits (revenues) of the duopolists as follows:

$$\pi_1 = \begin{cases} p_1(t_{12} - a) & t_{01} \leq a \\ p_1(t_{12} - t_{01}) & t_{01} > a, \end{cases}$$

$$\pi_2 = p_2(b - t_{12}).$$

3.3 A two-stage game: Quality-then-price

In this section we study a two-stage game in which two firms choose first their product qualities and then prices. Three different combination choices of business strategies mentioned in Section 1 will be studied for this duopoly. As in Chapter 2, we continuously restrict ourselves to the case where the income range of consumers $[a, b]$ satisfies the condition $2a < b < 4a$.

3.3.1 Competition at both stages

Given that two firms compete at both stages and that the income range of consumers satisfies the condition $2a < b < 4b$, we know from Chapter 2 and Shaked and Sutton (1982) that entry is blocked and the vertically differentiated market holds exactly two firms and all consumers buy from one of these firms. Therefore, the profits of the firms can be written as

$$\pi_1 = p_1(t_{12} - a), \text{ with } p_1 = t_{01} \leq a \tag{3.3.1}$$

and

$$\pi_2 = p_2(b - t_{12}). \tag{3.3.2}$$

Substituting (3.2.1) for t_{12} in (3.3.1) and (3.3.2) we calculate directly the Nash equilibrium prices and the associated profits of firms 1 and 2 as follows

$$p_1^n = \frac{q_2 - q_1}{3q_1}(b - 2a), \text{ with } p_1^n = t_{01} \leq a, \text{ and } p_2^n = \frac{q_2 - q_1}{3q_2}(2b - a);$$
$$\pi_1^n = \frac{q_2 - q_1}{9q_1}(b - 2a)^2, \text{ and } \pi_2^n = \frac{q_2 - q_1}{9q_2}(2b - a)^2.$$

Let $\alpha = q_1/q_2$ denote the degree of product differentiation and $\underline{\alpha} = q_m/q_M$ denote the maximum product differentiation. Then, $\underline{\alpha} \leq \alpha \leq 1$ and the lower the $\underline{\alpha}$ the larger the feasible product quality spectrum. The Nash equilibrium prices and the reduced profit function forms of firms can thus be written as

$$p_1^n = \frac{1-\alpha}{3\alpha}(b - 2a), \text{ with } p_1^n = t_{01} \leq a, \text{ and } p_2^n = \frac{1-\alpha}{3}(2b - a); \tag{3.3.3}$$
$$\pi_1^n = \frac{1-\alpha}{9\alpha}(b - 2a)^2, \text{ and } \pi_2^n = \frac{1-\alpha}{9}(2b - a)^2. \tag{3.3.4}$$

Differentiating the reduced profit function forms of both firms we have that $\partial\pi_1^n(\alpha)/\partial\alpha < 0$ and $\partial\pi_2^n(\alpha)/\partial\alpha < 0$. Therefore, the two firms will differentiate their products as much as possible at the first stage of quality competition in order to maximize their respective profits. That is, the firms prefer to keep α as small as possible. Considering that this differentiation is restricted by $t_{01} = p_1^n \leq a$, however, we have $\alpha \geq \frac{b-2a}{a+b}$. Thus, potentially the firms would keep the degree of their product differentiation at $\frac{b-2a}{a+b}$. Let α^{nn} denote the degree of product differentiation at equilibria, we have $\alpha^{nn} = max\{\underline{\alpha}, \frac{b-2a}{a+b}\}$. Summarizing, we have the following proposition.

Proposition 3.3.1 *Suppose two firms compete at both stages. Then, (i) if $\underline{\alpha} \geq \frac{b-2a}{a+b}$, there exists a unique subgame perfect equilibrium in pure strategies which exhibits maximum product differentiation, and the equilibrium prices and profits are*

$$p_1^{nn} = \frac{1-\underline{\alpha}}{3\underline{\alpha}}(b - 2a), \text{ and } p_2^{nn} = \frac{1-\underline{\alpha}}{3}(2b - a);$$
$$\pi_1^{nn} = \frac{1-\underline{\alpha}}{9\underline{\alpha}}(b - 2a)^2, \text{ and } \pi_2^{nn} = \frac{1-\underline{\alpha}}{9}(2b - a)^2.$$

(ii) Otherwise, there exist subgame perfect equilibria in pure strategies which exhibit product differentiation at the degree of $\frac{b-2a}{a+b}$. The equilibrium prices and profits are

$$p_1^{nn} = a, \text{ and } \pi_1^{nn} = \frac{a(b-2a)}{3};$$
$$p_2^{nn} = \frac{a(2b-a)}{a+b}, \text{ and } \pi_2^{nn} = \frac{a(2b-a)^2}{3(a+b)},$$

where nn denotes the competition at both stages.

Proof. We are only left to prove that the consequent equilibrium prices and profits hold. Substituting $\underline{\alpha}$ for α in (3.3.3) in the case (i) and $\frac{b-2a}{a+b}$ for α in (3.3.4) in the case (ii) leads directly to the equilibrium prices and profits.

□

3.3.2 Quality competition and price cooperation

In the second case, we consider a semicollusive version of the two-stage game, that is, two firms compete for their product quality specifications at the first stage of the game while both anticipate that price collusion will be sustained because of the trigger strategies played at the second stage of the game. The trigger strategies are defined as follows and we refer to this game as G^2.

Definition 3.3.1 Trigger strategies *are the standard grim strategies profile* $\{S_i^t\}$ *of an infinitely repeated price game for firm* $i, i \in \{1,2\}$ *at* $t = 1, 2, \ldots$ *and satisfy*

$$S_i^1 = p_i^c,$$

$$S_i^t = \begin{cases} p_i^c, & \text{if } S_j^\tau = p_j^c, \tau = 1, 2, ..., t-1, j \neq i; \\ p_i^n & \text{otherwise,} \end{cases}$$
$$t = 2, 3, ..., i = 1, 2,$$

where p_i^c *and* p_i^n *denote the collusion price and the Bertrand competition price, respectively.*

□

Price cooperation

In this chapter, firms are assumed to achieve their price cooperation through tacit collusion, which is sustained by trigger strategies. It is not obvious, however, how to introduce collusive pricing in an asymmetric game. One way to handle this problem is to follow the route which Friedman and Thisse (1993) have developed in dealing with the horizontal case, that is, to focus on collusive prices that support an outcome on the profit-possibility-frontier at which the market is assumed to be covered and that the profit-sharing rule regulates that the ratio of firm 1's profit to that of firm 2 is positively related to the same ratio of profits at the one-shot non-cooperative equilibrium. It is analytically difficult, however, to apply such a criterion. An alternative criterion is the joint-profit maximization rule stating that collusive prices maximize the size of the pie. This rule is analytically attractive and has been used in Hächner (1994). We will use the second rule for our subsequent analysis. More precisely, we assume that two firms charge prices to maximize their joint-profit at the second stage of the game for given q_1 and q_2. Two cases arise: partially covered market case versus entirely covered market case.

Partially covered market case. The first case that might arise is that the prices which maximize the joint-profit of firms may be so high that the market is not entirely covered. Then, the joint-profit is

$$\pi_1 + \pi_2 = p_1(t_{12} - p_1) + p_2(b - t_{12}),$$

which is a concave function. So setting the partial derivatives (w.r.t. p_1 and p_2) equal to zero yields the necessary and sufficient conditions for global profit maximization. The corresponding collusive prices are

$$p_1^c = \frac{(1+\alpha)b}{3+\alpha} \text{ and } p_2^c = \frac{2b}{3+\alpha}, \tag{3.3.5}$$

and the associated collusive profits are

$$\pi_1^c = \frac{(1+\alpha)b^2}{(3+\alpha)^2} \text{ and } \pi_2^c = \frac{2b^2}{(3+\alpha)^2}. \tag{3.3.6}$$

The partially covered market implies that $p_1^c > a$, or $\frac{1+\alpha}{3+\alpha}b > a$ from (3.3.5), holds. Otherwise, the entirely covered market case arises.

Entirely covered market case. In the second case that might arise, the market is entirely served at the prices that maximize joint-profit. Then, we have the joint-profit as

$$\pi_1 + \pi_2 = p_1(t_{12} - a) + p_2(b - t_{12}). \tag{3.3.7}$$

Obviously $p_1^c \leq a$. For $p_1^c < a$, both firms could raise prices by a small amount without taking a loss in terms of total demand. Joint-profits maximization must therefore imply $p_1^c = a$. Differentiating (3.3.7) with respect to p_2 yields

$$p_2^c = \frac{a(1+\alpha) + b(1-\alpha)}{2}. \tag{3.3.8}$$

The corresponding profits are

$$\pi_1^c = \frac{a(b-a)}{2} \text{ and } \pi_2^c = \frac{(b-a)[a(1+\alpha) + b(1-\alpha)]}{2}. \tag{3.3.9}$$

At the end of this section, we point out that the above derived collusive prices in a partially or an entirely covered market case can indeed be an equilibrium sustained by trigger strategies, to which Häckner's (1994) result applies directly. This result says that price collusion can be sustained as an equilibrium of trigger strategies between the two firms if each firm discounts its future profit at a certain level of $\gamma_i(\alpha), i = 1, 2$, $\gamma_1(\alpha)$ for firm 1 and $\gamma_i(\alpha)$ for firm 2. Moreover, these discount factors depend on α or the degree of product differentiation. For firm 2, the required discount factor decreases as the value of α increases, and approaches $\frac{1}{2}$ at the minimum product differntiation. For firm 1, however, the required discount factor may not be a decreasing function of α, but also approaches $\frac{1}{2}$ at the minimum product differntiation. The following lemma summarizes this result.

Lemma 3.3.1 *(Häckner, 1994, p.163 and p.169) Suppose that two firms, say firm 1 and firm 2, accept the joint-profit maximization rule if they collude on prices. Then, price collusion is an equilibrium sustained by trigger strategies of an infinitely repeated price game and the associated discount factors $\gamma_i(\alpha), i = 1, 2$. These discount factors are continuous functions of α. Moreover, $\gamma_2(\alpha)$ is decreasing and approaches $\gamma_2(1) = \frac{1}{2}$, and $\gamma_1(\alpha)$ approaches $\gamma_1(1) = \frac{1}{2}$.*

□

Lemma 3.3.1 has summarized the main result of Häckner's (1994). While Häckner studies the effects of quality specifications of firms on their price collusion sustainability, we may use this result, however, to study the effects of price collusion on quality specifications of firms. Lemma 3.3.1 shows that for any given qualities q_1 and q_2 of firms 1 and 2, respectively, price collusion may be sustained as an equilibrium of trigger strategies of an infinitely repeated price game at the price competition stage. The future discount factor required by this equilibrium depends on the degree of product differentiation α.

Given Lemma 3.3.1, we are now ready to turn to the proceeding stage of the process, in which firms compete for their product quality specifications.

Quality competition

In this section, we calculate the equilibrium of quality competition conditional on the reduced profit function forms of price collusion at the second stage of the game. Since price collusion may be an equilibrium sustained by trigger strategies under certain conditions, this equilibrium of quality competition at the first stage, if it exists, will also be a subgame perfect equilibrium of the semicollusion game G^2 under the same conditions. To discuss the existence of the subgame perfect equilibrium, we distinguish between the partially covered market case and the entirely covered market case.

Proposition 3.3.2 *In a partially covered market, there exists a unique subgame perfect equilibrium in pure strategies, in which two firms minimally differentiate their products and both choose the highest feasible product quality. The corresponding equilibrium prices and profits are*

$$p_1^{nc} = \frac{b}{2}, \; \textit{and} \; \pi_1^{nc} = \frac{b^2}{8}; \tag{3.3.10}$$

$$p_2^{nc} = \frac{b}{2}, \; \textit{and} \; \pi_2^{nc} = \frac{b^2}{8}, \tag{3.3.11}$$

where the superscript nc denotes that firms compete on qualities first and then collude on prices.

Proof. From Lemma 3.3.1, for deriving a subgame perfect equilibrium of the semicollusion game G^2 it is sufficient to derive a Nash equilibrium of the quality competition at the first stage of the game conditional on the reduced profit function forms (3.3.6) derived from the second stage of the game.

We first show that given an arbitrary quality pair of (q_1, q_2) at the first stage of the semicollusion game G^2, q_1 for firm 1, and q_2 for firm 2, the quality leader firm 2 has no incentives to jump over to set his product quality lower than that of firm 1. From (3.3.6) firm 2 gains

$$\pi_2^c(q_1, q_2^{'}) = \frac{2b^2}{(3+\alpha^{'})^2} \geq \frac{b^2}{8}, \alpha^{'} \in [\underline{\alpha}, 1], \tag{3.3.12}$$

if he sets his product quality at $q_2^{'}$ with $q_2^{'} \geq q_1$, and it gains

$$\pi_2^c(q_1, q_2^{''}) = \frac{(1+\alpha^{''})b^2}{(3+\alpha^{''})^2} \leq \frac{b^2}{8}, \alpha^{''} \in [\underline{\alpha}, 1] \tag{3.3.13}$$

if he sets his product quality at $q_2^{''}$ with $q_2^{''} \leq q_1$. Comparing (3.3.12) and (3.3.13), we see $\pi_2^c(q_1, q_2^{'}) \geq \pi_2^c(q_1, q_2^{''})$, so firm 2 will set q_2 such that $q_2 \geq q_1$.

Second, we show that firm 2 will set his product quality q_2 at q_M for any given q_1. This is straightforward because from (3.3.6) $\pi_2^c(\alpha)$ is a strictly decreasing function of α for $\alpha \in [\underline{\alpha}, 1]$.

Finally, we show that firm 1 will sets his product quality q_1 at q_M. In fact, from (3.3.4) $\pi_1^c(\alpha)$ is a strictly increasing function of α for $\alpha \in [\underline{\alpha}, 1]$. So, given that firm 2 chooses q_M, firm 1 maximizes his profit by choosing q_M also.

Summarizing, we conclude that there exists a unique subgame perfect equilibrium in pure strategies of the game G^2, in which both firms choose q_M. The corresponding prices and profits at the equilibrium are directly derived from substituting 1 for α in equations (3.3.5) - (3.3.6).

□

Proposition 3.3.3 *In an entirely covered market, there exists a continuum of subgame perfect equilibria, in which the quality leader chooses the highest feasible quality and the quality follower chooses randomly from the quality feasible spectrum. The equilibrium configurations are as follows.*

$$\overline{q}_1^{nc} \in [q_m, q_M], \overline{p}_1^{nc} = a, \text{ and } \overline{\pi}_1^{nc} = \frac{a(b-a)}{2};$$

$$\overline{q}_2^{nc} = q_M, \overline{p}_2^{nc} = \frac{a(1+\alpha) + b(1-\alpha)}{2},$$

and

$$\overline{\pi}_2^{nc} = \frac{(b-a)[a(1+\alpha)+b(1-\alpha)]}{2}, \textit{ for } \alpha = \overline{q}_1^{nc}/q_M \in [\underline{\alpha}, 1]. \tag{3.3.14}$$

Proof. From Lemma 3.3.1, for deriving a subgame perfect equilibrium of the semicollusion game G^2 it is sufficient to derive a Nash equilibrium of quality competition at the first stage of the game conditional on the reduced profit function forms (3.3.9) derived from the second stage of the game. Checking the reduced profit function forms (3.3.9) in the entirely covered market case, we find that $\pi_2^c(\alpha)$ is a strictly decreasing function of α while $\pi_1^c(\alpha)$ is independent of α. So, for any quality q_1 chosen by firm 1, firm 2 chooses q_M to maximize his profit. Firm 1 chooses randomly from the interval $[q_m, q_M]$. The equilibrium prices and profits are directly obtained from (3.3.8) and (3.3.9).

□

3.3.3 Cooperation at both stages

The third case deals with monopoly. Firms cooperate at both stages of the game. Again we distinguish between the partially covered market case and the entirely covered market case.

Partially covered market case. In this case, the collusive prices are given in equation (3.3.5), and the reduced function form of the joint-profit conditional on q_1 and q_2 is given by

$$\pi_1^c + \pi_2^c = \frac{b^2}{3+\alpha}. \tag{3.3.15}$$

This joint-profit function is strictly decreasing in α and therefore maximized at $\underline{\alpha}$. So, $q_1^{cc} = q_m$, $q_2^{cc} = q_M$ is the unique equilibrium of the quality competition at the first stage. Substituting $\underline{\alpha}$ for α in equation (3.3.5) leads to the following proposition.

Proposition 3.3.4 *There exists a unique subgame perfect equilibrium in a partially covered market, in which two firms differentiate their products maximally. The equilibrium* *prices and profit are as follows*

$$p_1^{cc} = \frac{b(1+\underline{\alpha})}{3+\underline{\alpha}}, p_2^{cc} = \frac{2b}{3+\underline{\alpha}}, \text{ and } \pi_1^{cc} + \pi_2^{cc} = \frac{b^2}{3+\underline{\alpha}}, \tag{3.3.16}$$

where the superscript cc denotes cooperation at both stages.

□

Entirely covered market case. In this case, the collusive prices are $p_1^c = a$ and p_2 as given in equation (3.3.6). The joint-profit conditional on q_1 and q_2 is given by

$$\pi_1^c + \pi_2^c = \frac{(b-a)[a(3+\alpha) + b(1-\alpha)]}{4}. \tag{3.3.17}$$

This joint-profit function is strictly decreasing in α and therefore maximized at $\underline{\alpha}$. So, $\overline{q}_1^{cc} = q_m$, $\overline{q}_2^{cc} = q_M$ is the unique equilibrium of the quality competition at the first stage. Substituting $\underline{\alpha}$ for α in equation (3.3.8) and (3.3.17) leads to the following proposition.

Proposition 3.3.5 *There exists a unique subgame perfect equilibrium in an entirely covered market, in which two firms differentiate their products maximally. The equilibrium prices and profit are as follows*

$$\overline{p}_1^{cc} = a, \overline{p}_2^{cc} = \frac{a(1+\underline{\alpha}) + b(1-\underline{\alpha})]}{2}, \tag{3.3.18}$$

and

$$\overline{\pi}_1^{cc} + \overline{\pi}_2^{cc} = \frac{(b-a)[a(3+\underline{\alpha}) + b(1-\underline{\alpha})]}{4}. \tag{3.3.19}$$

□

3.4 Comparative statics

Having derived Propositions 3.3.1-5, we are now in a position to compare the equilibrium configurations of firms under alternative combination choices of business strategies of qualities and prices. The consequences of the alternative business strategies are studied for qualities, prices, and profits, respectively.

3.4.1 Quality

A direct observation shows the significant effects of alternative business strategies on the degree of product differentiation of firms. In a vertically differentiated duopoly *à la* Shaked and Sutton (1982), competition on both qualities and prices leads the two firms to differentiate potentially their products at a degree of $\frac{b-2a}{a+b}$. Because this potential degree of product differentiation is constrained by the range of the feasible quality spectrum, the two firms will differentiate their products maximally if this potential degree of product differentiation is larger than the range of the feasible quality spectrum; otherwise, the potential degree of product differentiation will become the real degree of product differentiation exhibited between the two firms. In the former case, the equilibrium is unique, and the quality leader and follower choose the highest and lowest product qualities respectively. In the latter case, however, any choice of product qualities which exhibit a degree of product differentiation at $\frac{b-2a}{a+b}$ will be an equilibrium.

If both firms compete on qualities, and then collude on prices, the product differentiation behaviour of firms may be conditional on how high the collusive prices might be. If the collusive prices charged by the two firms are so high that some consumers choose not to buy from either firm, that is, the market is partially covered, then the two firms will pursue minimum differentiation and both choose the highest feasible quality product. If the collusive prices are relatively moderate so that all consumers prefer to buy from one of these firms, however, the product quality leader will prefer producing the highest feasible quality product. The product quality follower is, then, indifferent between producing any quality from the feasible quality spectrum and will randomly choose a feasible quality to produce.

Finally, cooperation on both qualities and prices leads the two firms to differentiate their products maximally.

This observation shows a parallel of a vertically differentiated, partially covered market case to that of horizontal differentiation. That is, if two firms play a two-stage semicollusive game, first competition, and then cooperation, the Hotelling's principle of minimum differentiation will be restored. In the former case, as demonstrated in this chapter, two firms minimize their product differentiation by both choosing the highest feasible product quality, while in the latter case, as shown in Jehiel (1992), and Friedman and Thisse (1993), two firms minimize their product differentiation and agglomerate at the market center.

This observation shows also some differences between horizontal and vertical differentiations. First of all, while competition at both stages, first on locations, and then on prices, leads two firms maximally differentiate their products in the horizontal case

(See d'Aspremont, Gabszewicz and Thisse (1979)), competition at both stages, first on qualities, and then on prices, leads, as shown in this chapter, only to some degree of vertical differentiation which is $\frac{b-2a}{a+b}$. This vertical differentiation is maximal only if this potential degree of $\frac{b-2a}{a+b}$ is larger than the range of the feasible quality spectrum of $\underline{\alpha}$. Moreover, while cooperation at both location and price stages exhibits some degree of horizontal differentiation and two firms locate at one quarter and three quarters of a unit interval, respectively (See Gabszewicz and Thisse (1979)), we show in this chapter that cooperation at both quality and price stages exhibit maximum vertical differentiation.

This observation has been derived by assuming away the effect of outside goods (i.e., $q_0 = 0$). Han and Webers (1996) shows, however, that outside goods do effect the degree of product differentiation. Although a comprehensive study on the principle of product differentiation by incorporating this factor is beyond our consideration, Chapters 2 and 3 indeed provide a classification on the degree of product differentiation under certain circumstances.

3.4.2 Price

We distinguish the partially covered market case from the entirely covered market case for the discussion of equilibrium prices. In the former case, the following result holds.

Proposition 3.4.1 *In a partially covered market, the following holds.*

$$p_1^{nc} \geq p_1^{cc} \geq p_1^{nn}; \text{ and}$$
$$p_2^{cc} \geq p_2^{nc} \geq p_2^{nn}.$$

Proof. First, let us check the equilibrium prices of firm 1. In the partially covered market we have, first of all, that $p_1^{cc} = \frac{b(1+\underline{\alpha})}{3+\underline{\alpha}} = \frac{b}{2}\frac{(3+\underline{\alpha})+(\underline{\alpha}-1)}{3+\underline{\alpha}} \leq \frac{b}{2} = p_1^{nc}$ since $\underline{\alpha} \leq 1$. Next, we show that $\frac{b(1+\underline{\alpha})}{3+\underline{\alpha}} \geq a$. Suppose that $\frac{b(1+\underline{\alpha})}{3+\underline{\alpha}} < a$. Rearranging this inequality we have $b - 2a + (1 + \underline{\alpha}(b-a)) < 0$, which contradicts the fact that $b > 2a$. Thus, we have that $p_1^{cc} \geq p_1^{nn}$ because $p_1^{nn} \leq a$.

Then, we check the equilibrium prices for firm 2. Direct comparison shows that $p_2^{cc} = \frac{2b}{3+\underline{\alpha}} \geq \frac{b}{2} = p_2^{nc}$ since $\underline{\alpha} \leq 1$. Moreover, let $p_2^{nc} \geq p_2^{nn}$, that is, let $\frac{b}{2} \geq \frac{a(2b-a)}{a+b}$, we have $(b-2a)(b-a) \geq 0$, which is true because $b > 2a$.

□

Proposition 3.4.1 shows that in a partially covered market the quality follower charges the highest price under semicollusion, a lower price under cooperation at both stages (full cooperation), and the lowest price under competition at both stages (full competition).

The quality leader, however, charges the highest price under full cooperation, a lower price under semicollusion, and the lowest price under full competition.

If the market is entirely covered, we may derive the following result.

Proposition 3.4.2 *In an entirely covered market, the following results are derived.*

$$\overline{p}_1^{cc} = \overline{p}_1^{nc} = a \geq p_1^{nn}; \textit{ and}$$
$$\overline{p}_2^{cc} \geq \overline{p}_2^{nc}, \textit{ and } \overline{p}_2^{cc} \geq p_2^{nn}.$$

Proof. For firm 1, that $\overline{p}_1^{cc} = \overline{p}_1^{nc} = a$ is directly from the Propositions 3.3.3 and 3.3.5. Moreover, from Proposition 3.3.1 we have that $p_1^{nn} \leq a$.

For firm 2, we have that $\overline{p}_2^{cc} = \frac{a(1+\underline{\alpha})+b(1-\underline{\alpha})}{2} \geq \frac{a(1+\alpha)+b(1-\alpha)}{2} = \overline{p}_2^{nc}$ because $\alpha \geq \underline{\alpha}$ and $b > a$. Furthermore, to require that $\overline{p}_2^{cc} \geq p_2^{nn}$ is equivalent to require that $\frac{a(1+\underline{\alpha})+b(1-\underline{\alpha})}{2} \geq \frac{a(2b-a)}{a+b}$ because the price p_1^{nn} under $\underline{\alpha} < \frac{b-2a}{a+b}$ is $\frac{a(2b-a)}{a+b}$, which is higher than the price p_1^{nn} under $\underline{\alpha} \geq \frac{b-2a}{a+b}$. But $\frac{a(1+\underline{\alpha})+b(1-\underline{\alpha})}{2} > \frac{a+b-\frac{b-2a}{a+b}(b-a)}{2}$ because $\underline{\alpha} < \frac{b-2a}{a+b}$. Moreover, $\frac{a+b-\frac{b-2a}{a+b}(b-a)}{2} = \frac{5ab-a^2}{2(a+b)} > \frac{a(2b-a)}{a+b}$. So, $\frac{a(1+\underline{\alpha})+b(1-\underline{\alpha})}{2} \geq \frac{a(2b-a)}{a+b}$ holds, that is, $p_2^{cc} \geq p_2^{nn}$.

□

Proposition 3.4.2 shows that in an entirely covered market the quality follower charges the same price under both semicollusion and full cooperation, which is not less than the price that he charges under full competition. The quality leader, however, charges a higher price under full cooperation than under semicollusion or full competition. Moreover, direct observation shows that the quality leader may charge a higher price under full competition than under semicollusion only if the degree of product differentiation under semicollusion is sufficiently large.

3.4.3 Profits

Finally, we distinguish the partially covered market case from the entirely covered market case for the discussion of the equilibrium profit configurations of firms. Comparison between these profits may lead firms to decide on the combination of business strategies of qualities and prices. First of all, in the partially covered market case, we have the following result.

Proposition 3.4.3 *Given that the market is partially covered, two firms will choose full cooperation.*

Proof. First of all, because $\underline{\alpha} \leq 1$, we have that $\pi_1^{nc} + \pi_2^{nc} = \frac{b^2}{8} + \frac{b^2}{8} = \frac{b^2}{4} \leq \frac{b^2}{3+\underline{\alpha}} = \pi^{cc}$. Therefore, the profits of both firms may be increased if two firms cooperate on both qualities and prices and a certain profit sharing rule is chosen. Thus, full cooperation is preferred to semicollusion. Then, we are left to compare the total profits under full competition and full cooperation.

If $\underline{\alpha} < \frac{b-2a}{a+b}$, then $\pi^{cc} = \frac{b^2}{3+\underline{\alpha}} \geq \frac{b^2(a+b)}{4b+a}$, and $\pi_1^{nn} + \pi_2^{nn} = \frac{a(b-2a)}{3} + \frac{a(2b-a)^2}{3(a+b)} = \frac{a(5b^2-5ab-a^2)}{3(a+b)}$. Thus, for proving that $\pi^{cc} \geq \pi_1^{nn} + \pi_2^{nn}$ it is sufficient to prove that $\frac{b^2(a+b)}{4b+a} \geq \frac{a(5b^2-5ab-a^2)}{3(a+b)}$, that is,

$$3b^4 - 14ab^3 + 18a^2b^2 + 9a^3b + a^4 \geq 0. \tag{3.4.1}$$

Let $b = (2+\epsilon)a$. Then, $\epsilon \in (0,2)$ because $2a < b < 4a$. Substituting $b = (2+\epsilon)a$ in (3.4.1) yields that $(2+\epsilon)^2(3\epsilon^2 - 2\epsilon + 2) + 9(2+\epsilon) + 1 \geq 0$, which holds for $\epsilon \in (0,2)$.

If $\underline{\alpha} \geq \frac{b-2a}{a+b}$, then $\pi_1^{nn} + \pi_2^{nn} = \frac{(1-\underline{\alpha})(b-2a)^2}{9\underline{\alpha}} + \frac{(1-\underline{\alpha})(2b-a)^2}{9} = \frac{(b-2a)^2}{9}\frac{1}{\underline{\alpha}} + \frac{b^2-a^2}{3} - \frac{(2b-a)^2}{9}\underline{\alpha} \leq \frac{(b-2a)^2}{9}\frac{b-2a}{a+b} + \frac{b^2-a^2}{3} - \frac{(2b-a)^2}{9}\underline{\alpha} = \frac{(a+b)(4b-5a)}{9} - \frac{(2b-a)^2}{9}\underline{\alpha}$. Thus, for proving that $\pi^{cc} \geq \pi_1^{nn} + \pi_2^{nn}$ it is sufficient to prove that $(a+b)(4b-5a) - (2b-a)^2\underline{\alpha} \leq \frac{9b^2}{3+\underline{\alpha}}$, that is, $(a+b)(4b-5a) \leq (2b-a)^2\underline{\alpha} + \frac{9b^2}{3+\underline{\alpha}}$. Because the right hand side of this inequality is an increasing function of $\underline{\alpha}$, it is sufficient to prove that $(a+b)(4b-5a) \leq (2b-a)^2\frac{b-2a}{a+b} + \frac{9b^2}{3+\frac{b-2a}{a+b}}$. Simplification shows that this last inequality is equivalent to (3.4.1), which has been proved to hold.

Therefore, the total profit under full cooperation is higher than that both under semicollusion and under full competition. The profits of both firms could be increased through full cooperation and a properate profit sharing rule. Thus, full cooperation emerges as the preferred business strategies for both firms.

□

If the market is entirely covered, we have the following proposition.

Proposition 3.4.4 *Given that the market is entirely covered, two firms will choose full cooperation.*

Proof. First of all, we have that $\pi_1^{nc}+\pi_2^{nc}=\frac{a(b-a)}{2}+\frac{(b-a)[a(1+\alpha)+b(1-\alpha)]}{4}=\frac{(b-a)[a(3+\alpha)+b(1-\alpha)]}{4}\leq\frac{(b-a)[a(3+\underline{\alpha})+b(1-\underline{\alpha})]}{4}=\overline{\pi}^{cc}$ because $\underline{\alpha}\leq\alpha$. Thus, two firms prefer full cooperation to semi-collusion because their profits may be increased through full cooperation and a certain profit sharing rule. Then, we are left to prove that their profits under full competition may be increased through full cooperation and a certain profit sharing rule.

If $\underline{\alpha}<\frac{b-2a}{a+b}$, we have $\pi_1^{nn}=\frac{a(b-2a)}{3}$ and $\pi_2^{nn}=\frac{a(2b-a)^2}{3(a+b)}$. So, $\pi_1^{nn}+\pi_2^{nn}=\frac{a(5b^2-5ab-a^2)}{3(a+b)}$. Moreover, we have that $\overline{\pi}^{cc}=\frac{(b-a)[a(3+\underline{\alpha})+b(1-\underline{\alpha})]}{4}\geq\frac{(b-a)[3a+b-\frac{b-2a}{a+b}(b-a)]}{4}=\frac{a(b-a)(a+7b)}{4(a+b)}$. Let $\frac{a(b-a)(a+7b)}{4(a+b)}\geq\frac{a(5b^2-5ab-a^2)}{3(a+b)}$, we have that $(a+b)^2\geq 0$, which is trivial. Therefore, that $\pi_1^{nn}+\pi_2^{nn}\leq\overline{\pi}^{cc}$ holds.

If $\underline{\alpha}\geq\frac{b-2a}{a+b}$, we have $\pi_1^{nn}=\frac{(1-\underline{\alpha})(b-2a)^2}{9\underline{\alpha}}$ and $\pi_2^{nn}=\frac{(1-\underline{\alpha})(2b-a)^2}{9}$. So, $\pi_1^{nn}+\pi_2^{nn}=\frac{(1-\underline{\alpha})[(b-2a)^2+(2b-a)^2\underline{\alpha}]}{9\underline{\alpha}}$. If $\pi_1^{nn}+\pi_2^{nn}>\overline{\pi}^{cc}$, we then have that $\frac{(1-\underline{\alpha})[(b-2a)^2+(2b-a)^2\underline{\alpha}]}{9\underline{\alpha}}>\overline{\pi}^{cc}=\frac{(b-a)[a(3+\underline{\alpha})+b(1-\underline{\alpha})]}{4}$. Simplification shows that $[(a+b)(7b-5a)]\underline{\alpha}^2-3(b-a)(b-5a)\underline{\alpha}-4(b-2a)^2<0$. Thus, $\frac{(7b-5a)(b-2a)^2}{a+b}-3(b-a)(b-5a)\frac{b-2a}{a+b}-4(b-2a)^2<0$. Further simplification shows that $a+b<0$, which contradicts to the fact that $a>0, b>0$. Therefore, we have that $\pi_1^{nn}+\pi_2^{nn}\leq\overline{\pi}^{cc}$.

Summarizing, we have that the total profit under full cooperation is the highest in an entirely covered market. The profits of both firms may, then, be increased through full cooperation and a certain profit sharing rule. Therefore, they will choose full cooperation.

□

3.5 Concluding remarks

Despite of the similarity between the horizontal differentiation setting and the vertical differentiation setting, important differences do exist between these two settings. For example, Gabszewicz and Thisse (1986, 1992) find that horizontal differentiation exhibits less stability than vertical differentiation. Moreover, horizontal differentiation leads to market 'fragmentation', that is, the level of market concentration falls as the size of the economy increases and in the limit a horizontally differentiated market may hold an arbitrarily large number of firms as the size of the economy goes to infinity. Vertical differentiation, however, may lead to market concentration. As shown in Shaked and Sutton (1983), if the unit variable costs associated with product quality improvement rise more slowly than the willingness to pay of consumers or if the main burden of quality improvement falls on sunk costs rather than variable costs, the market may hold only a certain number of firms, that is, the 'finiteness' property holds in a vertically differentiated market. In other words, there is a limit to the number of firms with prices exceeding unit variable costs, and with each firm having a positive market share. Furthermore, this maximum number is independent of the set of the products being offered, of the size of the sunk costs, and of the number of potential consumers. What is determinant is, in fact, the range of the income distributions of consumers.

Also different is the relationship between product differentiation and collusion sustainability. While this relationship is positive, as shown in Chang (1991), in a horizontal differentiation model *à la* Hotelling (1929), it is shown negative by Häckner (1994) in a vertical differentiation model *à la* Shaked and Sutton (1982).

In this chapter, three different combination of choices of business strategies of qualities and prices and their effects on the degree of product differentiation are studied for a vertically differentiated duopoly. Two firms play a two-stage game and decide, first, on quality, and then, on price. They maximize their joint-profit if they cooperate. It is shown that the profit of the two firms is higher under full cooperation than under semicollusion or cooperation at both stages. Therefore, both firms may increase their profits if they cooperate at both stages and agree on a propriate profit sharing rule. Thus, cooperation may eventually emerge as a unique subgame perfect equilibrium of this two-stage game, and the two firms differentiate their products maximally. Moreover, the product quality follower will charge a full cooperation price lower than the semicollusion price, but higher than the full competition price. The product quality leader, however, will charge a full cooperation price higher than either semicollusion or full competition price.

Our analyses have shown further similarities between the horizontal and vertical differentiations. For example, Hotelling's (1929) principle of minimum differentiation is restored and fostered by semicollusion in both horizontal and vertical differentiations. Jehiel (1992) and Friedman and Thisse (1993) show in horizontal differentiation models *à la* Hotelling (1929) that two firms may agglomerate at the market center if they compete, first, at the location stage, and then collude at the price stage. We show in a vertical differentiation model *à la* Shaked and Sutton (1983) that two firms may both choose the highest feasible product quality if they compete, first, at the quality specification stage, and then collude at the price stage.

Further difference, however, has also been discovered. While cooperation at both location and price stages exhibits some degree of horizontal differentiation and two firms locate at one quarter and three quarters of a unit interval (See Gabszewicz and Thisse (1979)), we show in this chapter that cooperation at both quality specification and price stages exhibit maximum vertical differentiation. That is, the two firms choose the highest and lowest feasible product qualities, respectively.

References

CHANG, M.H., 1991, "The Effects of Product Differentiation on Collusive Pricing", *International Journal of Industrial Organization*, 9, 453-470.

DAVIDSON, C. AND R., DENECKERE, 1990, "Excess Capacity and Collusion", *International Economic Review*, 31, 521-541.

DONNENFELD, S. AND S., WEBER, 1992, "Vertical Product Differentiation with Entry", *International Journal of Industrial Organization*, 10, 449-472.

FERSHTMAN, C. AND N., GANDAL, 1994, "Disadvantageous Semicollusion", *International Journal of Industrial Organization*, 12, 141-154.

FRIEDMAN, J.W. AND J.-F., THISSE, 1993, "Partial Collusion Fosters Minimum Product Differentiation", *RAND Journal of Economics*, 24, 631-645.

GABSZEWICZ, J.J. AND J.-F., THISSE, 1986, "On the Nature of Competition with Differentiated Products", *The Economic Journal*, 96, 160-172.

HÄCKNER, J., 1994, "Collusive Pricing in Markets for Vertically Differentiated Products", *International Journal of Industrial Organization*, 12, 155-177.

HAN, X. AND H., WEBERS, 1996, "A Comment on Shaked and Sutton's Model of Vertical Product Differentiation", CentER Discussion Paper, No. 9666, Tilburg University, Tilburg.

HOTELLING, H., 1929, "Stability in Competition", *Economic Journal*, 39, 41-57.

JACQUEMIN, A. AND M.E., SLADE, 1989, "Cartel, Collusion and Horizontal Merger", in: R. Schmalensee and R. Willig, eds., *Handbook of Industrial Organization*, North-Holland, Amsterdam, 415-473.

JEHIEL, P., 1992, "Product Differentiation and Price Collusion", *International Journal of Industrial Organization*, 10, 633-641.

MATSUI, A., 1989, "Consumer-benefitted Cartels under Strategic Capital Investment Competition", *International Journal of Industrial Organization*, 7, 451-470.

OSBORNE, M. AND C., PITCHIK, 1987, "Cartels, Profits and Excess Capacity", *International Economic Review*, 28, 413-428.

SCHERER, F., 1980, *International Market Structure and Economic Performence*, Houghton-Mifflin, Boston.

SEVY, D., 1992, "Faut-il Reguler la *R&D*"? Document de Travail 371, Laboratoire d'Econometrie de l'Ecole Polytechnique, Paris.

SHAKED, A. AND J., SUTTON, 1982, "Relaxing Price Competition Through Product Differentiation", *Review of Economic Studies*, XLIX, 3-13.

SHAKED, A. AND J., SUTTON, 1983, "Natural Oligopolies", *Econometrica*, 51, 1469-1483.

SHAPIRO, C., 1989, "Theory of Oligopoly Behavior", in: R. Schmalensee and R. Willig, eds., *Handbook of Industrial Organization*, North-Holland, Amsterdam.

TIROLE, J., 1988, *The theory of industrial organization*, The MIT Press, Cambridge.

Chapter 4

Product differentiation with concentrated consumer distributions: The location-then-price games

4.1 Introduction

Hotelling's (1929) *spatial competition* model has been studied by distinguishing between the *inside and outside location games.*[1] In the inside location game, firms may locate inside the residential area where consumers live. This is the "Main Business Street" model of Hotelling (1929). The opposite is the outside location game, in which firms are regulated to locate outside the residential area, just like that some shops locate at the outskirt of a city. Gabszewicz and Thisse (1986) show that the nature of competition of inside and outside location games turn out to be quite different. That is, while the former corresponds to horizontal differentiation the latter represents vertical differentiation. In the inside location game, consumers appear to differ in their tastes because they prefer to buy from closer firms considering transportation costs. Therefore, at the same price charged by firms, some consumers choose to buy from one firm while the others choose alternative ones and so horizontal differentiation prevails. On the other hand, in the outside location game, one firm locates closer to all consumers than the others. Therefore, at the same price all consumers may prefer to buy from this closer firm rather than the others considering transportation costs. Consequently, vertical differentiation prevails.

[1]See Gabszewicz and Thisse (1986, 1992), for examples.

Although a uniform distribution of consumers has been assumed in most of the studies, an increasing density of consumers toward the market centre seems, intuitively, more realistic. In particular, a concentrated distribution of consumers arises in a vertically differentiated market where consumers are assumed to be distributed by their incomes (a normal distribution is an obvious candidate). Accordingly, it seems important to analyse whether, and how, the competition of firms is modified by these non-uniform and concentrated consumer distributions, on which we shall focus in this chapter.

A priori, one might wonder how a non-uniform and concentrated consumer distribution modifies the competition between firms. It has been shown in the inside location game that under the uniform consumer distribution, *price competition force* drives firms to locate apart in order to relax price competition.[2] When consumer distributions are non-uniform and concentrated, however, *market retention force* arises, which attracts firms to locate toward the high consumer density area. This means that firms have incentives to locate toward the market centre if it is the area where consumers are concentrated. Then, in the inside location games market retention force attracts firms to locate closer to each other. Therefore, price competition force and market retention force are two countervailing forces that effect the locations of firms or the degree of product differentiation. The domination of one force over the other will decide either an increased or a decreased product differentiation. On the other hand, in the outside location game, some firms locate closer to the consumers than the others. This location difference creates an asymmetry between the firms, and provides the firms locating closer to the consumers an advantage over the others. The concentration of consumer distribution around the market center increases the market shares of the firms that locate closer to the consumers while decreases the market shares of the others. Then, the asymmetry is further increased. As a result, the firms locating farther from consumers want more product differentiation to relax price competition, and product differentiation is thus increased.

Because of the analytic difficulty, however, few studies have been found to analyse this trade-off, except for Neven (1986). Neven considers Hotelling's competition with symmetric, continuous, and concave consumer distributions. Following d'Aspremont, Gabszewicz and Thisse (1979) he assumes a quadratic transportation cost function. Different from the finding of d'Aspremont, Gabszewicz and Thisse (1979), however, is that there exists a range of symmetric and concave consumer distributions over which duopolists differentiate their products maximally, that is, they locate at the ends of the market. When the consumer distributions become more concentrated, the duopolists tend to move toward the inside of the market, thus decrease their product differentiation.

[2]See d'Aspremont, Gabszewicz and Thisse (1979), and Gabszewicz and Thisse (1986).

Related studies have also been found recently following Caplin and Nalebuff (1991) who provide conditions on the existence and uniqueness of the equilibrium of price competition for generalised consumer distributions - log-concave consumer distributions. Goeree and Ramer (1994), for example, consider Hotelling's competition with removed location restrictions. That is, both consumers and firms may choose locations from the whole real line. They provide conditions on the existence of a subgame perfect equilibrium of Hotelling's competition. In a similar setting Tabuchi and Thisse (1995) find asymmetric equilibria. Restoring location restrictions allows one to study inside and outside location games or horizontal and vertical differentiation games, but may not guarantee the existence of the equilibrium.

In this chapter, we try to restore the location restrictions in order to study inside and outside location games. For this study, we follow a setting of Gabszewicz and Thisse (1986). We show that additional insights may be added to the effect of concentrated consumer distributions on the locations of firms.

More precisely, we study Hotelling's spatial competition to examine the effect of concentrated consumer distributions on the degree of product differentiation. Two firms play a two-stage game non-cooperatively, first locations and then prices. They may locate either inside or outside of the residential area where consumers live.

For convenience, and also to compare the results derived in this chapter with that of Gabszewicz and Thisse (1986), we restrict ourselves to quadratic transportation costs in the inside location game and to linear-quadratic transportation costs in the outside location game. As usual, we seek subgame perfect equilibria of the two-stage game in which firms select locations first and then set up their prices.

We show, for the inside location game, that rather flat consumer distributions lead the two firms to differentiate their products maximally, and when consumer distributions become more concentrated the duopolists tend to move inside the market. We further show that precommitment of firms to symmetric locations leads to maximum differentiation, which is independent of concentrated consumer distributions. For the outside location game, however, product differentiation is increased when consumers are concentrated around the market center.

Our results in the inside location game differ sharply from Neven (1986) in the case when firms *ex ante* commit to symmetric locations at the first stage of the game. Otherwise, the results derived here include the result derived in Neven (1986) as a special case. This is because consumer distributions are more general (log-concave) than those given by Neven (concave).

The remainder of this chapter is organized as follows. The model is presented in

Section 4.2. Sections 4.3 and 4.4 are concerned with inside and outside location games, respectively. In these two sections, the trade-off between price competition force and market retention force is analysed and the effect of consumer concentrations on the degree of product differentiation is examined. Section 4.5 concludes.

4.2 The model

There are two firms, firm 1 and firm 2, producing a homogeneous good at constant marginal costs which are normalized to zero. These two firms play a two-stage game non-cooperatively. They compete first on locations, and then on prices. The location and price of firm i with $i \in \{1,2\}$ are noticed by s_i and p_i, respectively. We distinguish between inside and outside location games. Two firms choose their locations over the residential area $[0,1]$ in the inside location game, and over $[1,+\infty)$, or outside the residential area, in the outside location game. Without loss of generality, we assume that $s_1 < s_2$. Otherwise Bertrand competition prevails if $s_1 = s_2$.

Consumers are distributed over a residential area which is normalized to $[0,1]$. The consumer distribution density function and the cumulative distribution function of consumers are represented by $f(.)$ and $F(.)$, respectively. Consumers are assumed to have identical preferences and to buy one unit product exclusively from one of the firms. The reservation price of consumers is infinite, which means that all consumers prefer to buy from either firm. Transportation costs are assumed to be quadratic in the inside location game, and to be linear-quadratic in the outside location game. Therefore, a consumer residing at x will buy from firm i where $i = argmin_{j\in\{1,2\}}[p_j + (s_j - x)^2]$ in the inside location game, and from firm i where $i = argmin_{j\in\{1,2\}}[p_j + c(s_j - x) + d(s_j - x)^2]$ in the outside location game, where c, d are constants, and $c, d > 0$.

Consequently, at the same price charged by the two firms in the inside location game, some consumers prefer to buy from firm 1 while the others prefer to buy from firm 2. Therefore, their tastes appear to be diverse. In the outside location game, however, if two firms charge the same price, all consumers will prefer the product from firm 1 to that from firm 2. This is because firm 1 is closer to all consumers than firm 2, and it is, therefore, cheaper for all consumers to buy from firm 1 than from firm 2. In other words, it seems that all consumers rank good 1 higher than good 2 because of the fact that $s_1 < s_2$. This allows obviously for an interpretation in term of quality. So, the inside and the outside location games represent horizontal and vertical product differentiations, respectively. Moreover, beyond the location restrictions it is regarded either technologically or economically infeasible.

At the end of this section, we introduce our main restrictions on the consumer distributions. First of all, a ρ-concave function is defined as follows.

Definition 4.2.1 *Let $\rho > 0$. A function f: $B \to \Re_+$, with $B \subset \Re$ being an interval, is* ρ**-concave** *if for every $x_0, x_1 \in B$, and for every $\lambda \in [0,1]$ it holds that*

$$f(x_\lambda) \geq [(1-\lambda)(f(x_0))^\rho + \lambda(f(x_1))^\rho]^{1/\rho}, \tag{4.2.1}$$

where $x_\lambda \equiv (1-\lambda)x_0 + \lambda x_1$.

□

For $\rho < 0$ the definition of $\rho-$*concavity* is the same as above definition except when $f(x_0)f(x_1) = 0$, in which case there is no restriction other than $f(x_\lambda) \geq 0$. Finally, the definition may be extended to include $\rho = -\infty, 0, +\infty$ through continuity arguments.

For $\rho = 0$, (4.2.1) is equivalent to concavity of $log(f)$. In the sequel we shall use the term log-concave instead of 0-concave. It can be shown that the higher value of ρ corresponds to the more stringent variant of concavity, that is, a ρ-concave function is also a ρ'-concave function for every $\rho' \leq \rho$. Moreover, if the function $f(.)$ is twice differentiable, then the log-concavity is equivalent to the following second-order condition.

$$f''(x)f(x) - f'(x)f'(x) \leq 0, \text{ for every } x \in supp(f), \tag{4.2.2}$$

where $supp(f)$ denotes the support of $f(.)$, that is, $f(x) > 0$ for $x \in supp(f)$.

We may distinguish between inside and outside location games to study the trade-off between price competition force and market retention force, for which the following assumption will be repeatedly used.

Assumption 4.2.1 *The consumer density function $f(.)$ is log-concave and differentiable over the interval $[0,1]$. Moreover, $f(x) > 0$ for all $x \in (0,1)$.*

□

4.3 The inside location game

Let us first examine the effect of concentrated consumer distributions on the locations of firms or on the degree of product differentiation for the inside location game. Following the commonly used backwards induction analysis procedure, we focus, first of all, on the second stage of the game to derive the equilibrium levels of prices.

4.3.1 Price competition

Let the locations of the two firms be given, s_1 for firm 1, s_2 for firm 2, and $s_1, s_2 \in [0,1]$. Without loss of generality we assume that $s_1 < s_2$. Moreover, suppose that transportation costs are quadratic. Then, the delivering price that a consumer residing at x has to pay is $p_1 + (s_1 - x)^2$ if she buys from firm 1, and $p_2 + (s_2 - x)^2$ if she buys from firm 2. A consumer will buy from a firm to which she pays a lower total price. The *marginal consumer* who is indifferent between buying from either firm is, therefore, residing at

$$\xi(s_1, s_2, p_1, p_2) = \frac{1}{2}(s_1 + s_2 + \frac{p_2 - p_1}{s_2 - s_1}). \tag{4.3.1}$$

Thus, firms 1 and 2 segment the market by $D_1 = F(\xi(s_1, s_2, p_1, p_2))$ and $D_2 = 1 - F(\xi(s_1, s_2, p_1, p_2))$, respectively, where $F(\xi) \equiv \int_0^\xi f(x)dx$. The two firms' profits are as follows

$$\pi_1(s_1, s_2, p_1, p_2) = p_1 F(\xi(s_1, s_2, p_1, p_2)), \tag{4.3.2}$$

$$\pi_2(s_1, s_2, p_1, p_2) = p_2(1 - F(\xi(s_1, s_2, p_1, p_2))). \tag{4.3.3}$$

Thanks to Caplin and Nalebuff (1991), we may then derive the following lemma.

Lemma 4.3.1 *Suppose that transportation costs are quadratic and Assumption 4.2.1 holds. Then, there exists a unique equilibrium of price competition for any given locations of the two firms. The equilibrium levels of prices and profits are*

$$p_1^*(s_1, s_2) = 2(s_2 - s_1)F(\xi^*(s_1, s_2))/f(\xi^*(s_1, s_2)), \tag{4.3.4}$$

$$p_2^*(s_1, s_2) = 2(s_2 - s_1)[1 - F(\xi^*(s_1, s_2))]/f(\xi^*(s_1, s_2)), \tag{4.3.5}$$

$$\pi_1^*(s_1, s_2) = 2(s_2 - s_1)F^2(\xi^*(s_1, s_2))/f(\xi^*(s_1, s_2)), \tag{4.3.6}$$

$$\pi_2^*(s_1, s_2) = 2(s_2 - s_1)[1 - F(\xi^*(s_1, s_2))]^2/f(\xi^*(s_1, s_2)), \tag{4.3.7}$$

where $\xi^*(s_1, s_2) = \xi(s_1, s_2, p_1^*(s_1, s_2), p_2^*(s_1, s_2))$.

Proof. Given the conditions that transportation costs are quadratic and Assumption 4.2.1 holds, the finding of Caplin and Nalebuff (1991) applies directly to guarantee the existence and the uniqueness of the price equilibrium. We are then left with calculating the equilibrium configurations using the first order condition.

Differentiating (4.3.2) and (4.3.3) with respect to p_1 and p_2, respectively, yields

$$\frac{\partial \pi_1}{\partial p_1} = F(\xi^*(s_1, s_2)) + p_1 f(\xi^*(s_1, s_2)) \frac{1}{2} \frac{-1}{s_2 - s_1} = 0, \tag{4.3.8}$$

$$\frac{\partial \pi_2}{\partial p_2} = (1 - F(\xi^*(s_1, s_2))) + p_2 \frac{-f(\xi^*(s_1, s_2))}{2} \frac{1}{s_2 - s_1} = 0. \tag{4.3.9}$$

Solving equations (4.3.8) and (4.3.9) for p_1^* and p_2^*, respectively, and then substituting p_1^* and p_2^* for p_1 and p_2 in equations (4.3.2) and (4.3.3) yield the equilibrium levels of the two firms' prices and profits.

□

The marginal consumer's reduced form at the price equilibrium may be derived as follows. Subtracting (4.3.4) from (4.3.5) we have the expression of $p_2^*(s_1, s_2) - p_1^*(s_1, s_2)$. Substituting this expression for $p_2(s_1, s_2) - p_1(s_1, s_2)$ in (4.3.1) yields the marginal consumer's location at the price equilibrium defined by the following implicit equation

$$\xi^*(s_1, s_2) = \frac{1}{2}(s_1 + s_2) + \frac{1 - 2F(\xi^*(s_1, s_2))}{f(\xi^*(s_1, s_2))}. \tag{4.3.10}$$

Differentiating (4.3.10) yields directly the following lemma.

Lemma 4.3.2 $\partial \xi^*(s_1, s_2)/\partial s_1 = \partial \xi^*(s_1, s_2)/\partial s_2 = f^2(\xi^*(s_1, s_2))/[6f^2(\xi^*(s_1, s_2)) + 2(1 - 2F(\xi^*(s_1, s_2)))f'(\xi^*(s_1, s_2))]$.

□

Given Lemma 4.3.1, we have well defined reduced profit function forms of the two firms conditional on their locations s_1 and s_2. We now turn to the preceding stage of the game to consider location competition between the two firms.

4.3.2 Location competition

Turning to the location stage of the game, we know that an equilibrium of the location game is a location pair of $s^* = (s_1^*, s_2^*)$ such that s_i^* maximizes $\pi_i^*(s_i, s_j^*)$ with respect to s_i for given s_j^* (i, j = 1, 2 and $i \neq j$). Therefore, the first order condition applies to generate the necessary conditions of a location equilibrium.[3] First of all, we may derive the following lemma.

Lemma 4.3.3 *Let the marginal consumer's location at the price equilibrium be given in (4.3.10). Then, at the location equilibrium (s_1^*, s_2^*) it follows that*

$$2 - 2F(\xi^*(s_1^*, s_2^*)) + 2F^2(\xi^*(s_1^*, s_2^*)) = (s_2^* - s_1^*)f(\xi^*(s_1^*, s_2^*)). \tag{4.3.11}$$

Proof.[4] From Lemma 4.3.2 we define $\delta = \partial\xi^*(s_1, s_2)/\partial s_1 = \partial\xi^*(s_1, s_2)/\partial s_2$ and $\xi = \xi^*(s_1, s_2)$. Then, differentiating (4.3.6) with respect to s_1, (4.3.7) with respect to s_2, and setting the derivatives equal to zero yields

$$\frac{\partial\pi_1^*(s_1, s_2)}{\partial s_1} = -\tfrac{F^2(\xi)}{f(\xi)} + 2(s_2 - s_1)F(\xi)\delta - (s_2 - s_1)\tfrac{F^2(\xi)f'(\xi)\delta}{f^2(\xi)} = 0, \tag{4.3.12}$$

$$\frac{\partial\pi_2^*(s_1, s_2)}{\partial s_2} = \tfrac{[1-F(\xi)]^2}{f(\xi)} - 2(s_2 - s_1)[1 - F(\xi)]\delta - (s_2 - s_1)\tfrac{[1-F(\xi)]^2 f'(\xi)\delta}{f^2(\xi)}$$

$$= 0. \tag{4.3.13}$$

Eliminating δ from equations (4.3.12) and (4.3.13) yields

$$[1 - 2F(\xi)]f^2(\xi) - [1 - F(\xi)]F(\xi)f'(\xi) = 0, \tag{4.3.14}$$

while taking the sum of equations (4.3.12) and (4.3.13) yields

$$f(\xi)(1 - 2F(\xi)) = (s_2 - s_1)f'(\xi)\partial\xi^*/\partial s_1,$$

[3] We may not be able to guarantee, *a priori*, that s^* as such derived is an equilibrium location pair since s_1^* and s_2^* may not fall into $[0, 1]$.

[4] An alternative proof is provided in Goeree and Ramer (1994). We provide, however, a modified version of their proof for later use.

which can be rewritten as

$$F(\xi)(1-F(\xi)) = (s_2 - s_1)f(\xi)\partial\xi^*/\partial s_1, \tag{4.3.15}$$

by making use of (4.3.14). Rewriting $\partial\xi^*/\partial s_1$ of Lemma 4.3.2 by making use of (4.3.14) we have $\partial\xi^*/\partial s_1 = F(\xi)(1-F(\xi))/(2-2F(\xi)+2F^2(\xi))$. Substituting this expression for $\partial\xi^*/\partial s_1$ in (4.3.15) gives (4.3.11).

□

Lemma 4.3.3 implies that at the price equilibrium, two firms locate apart by $s_2^* - s_1^* = \frac{2-2F(\xi^*(s_1^*,s_2^*))+2F^2(\xi^*(s_1^*,s_2^*))}{f(\xi^*(s_1^*,s_2^*))}$, which is the degree of product differentiation. Without imposing any restriction on the locations of firms, we may then derive the following necessary conditions of a location equilibrium.

Corollary 4.3.1 *Under Assumption 4.2.1, a subgame perfect equilibrium $(s_1^*, s_2^*, p_1^*, p_2^*)$ without location restrictions must satisfy*

$$\begin{aligned}
s_1^* &= \xi^* - \tfrac{(1-F(\xi^*))(2-F(\xi^*))}{f(\xi^*)},\\
s_2^* &= \xi^* + \tfrac{F(\xi^*)(1+F(\xi^*))}{f(\xi^*)},\\
p_1^* &= \tfrac{4F(\xi^*)(1-F(\xi^*)+F^2(\xi^*))}{f^2(\xi^*)},\\
p_2^* &= \tfrac{4(1-F(\xi^*))(1-F(\xi^*)+F^2(\xi^*))}{f^2(\xi^*)},
\end{aligned}$$

and yielding profits

$$\begin{aligned}
\pi_1^* &= \tfrac{4F^2(\xi^*)(1-F(\xi^*)+F^2(\xi^*))}{f^2(\xi^*)},\\
\pi_2^* &= \tfrac{4(1-F(\xi^*))^2(1-F(\xi^*)+F^2(\xi^*))}{f^2(\xi^*)},
\end{aligned}$$

where ξ^* is the solution to (4.3.14).

Proof. Solving equations (4.3.12) and (4.3.13) yields s_1^* and s_2^*. Substituting $s_2^* - s_1^*$ of equation (4.3.11) for $s_2 - s_1$ in equations (4.3.4), (4.3.5), (4.3.6) and (4.3.7) yield p_1^*, p_2^*,

π_1^* and π_2^*.

□

To derive a subgame perfect equilibrium, we may further specify the consumer density function $f(.)$ to be symmetric. Then $\xi^* = F(\xi^*) = \frac{1}{2}$. Substituting them into the equilibrium configurations of Corollary 4.3.1 leads directly to the following corollary.

Corollary 4.3.2 *Suppose that the consumer distribution density function $f(.)$ is symmetric. Then, under Assumption 4.2.1 a subgame perfect equilibrium $(s_1^*, s_2^*, p_1^*, p_2^*)$ of the inside location game satisfies*

$$\begin{aligned} s_1^* &= \tfrac{1}{2} - \tfrac{3}{4f(1/2)}, \\ s_2^* &= \tfrac{1}{2} + \tfrac{3}{4f(1/2)}, \\ p_1^* &= p_2^* = \tfrac{3}{2f^2(1/2)}, \end{aligned}$$

and yields profits

$$\pi_1^* = \pi_2^* = \frac{3}{4f^2(1/2)}.$$

□

This corollary shows that the two firms will locate at the ends of the market until the concentration of the consumer distributions around the the market centre increases to a sufficiently high level, that is, until the value of $f(\frac{1}{2})$ reaches $3/2$. Thereafter, the two firms intend to move toward inside the market as the concentration of the consumer distribution around the market centre, measured by the value of $f(\frac{1}{2})$, increases. In other words, the two firms will maximally differentiate their products if the consumer distribution density function is symmetric and the value of $f(.)$ at the market centre is less than $3/2$. Otherwise, they intend to decrease their product differentiation by moving toward inside the market as the value of $f(.)$ at the market centre is higher than $3/2$ and increases. The following proposition summarizes the main result thus far.

Proposition 4.3.1 *Suppose that the consumer distribution density function $f(.)$ is symmetric. Then, under Assumption 4.2.1 there exists a unique subgame perfect equilibrium of the inside location game, in which the equilibrium configurations hold as*

$$\begin{aligned} s_1^* &= 0, s_2^* = 1, \\ p_1^* &= p_2^* = \tfrac{1}{f(\frac{1}{2})}, \\ \pi_1^* &= \pi_2^* = \tfrac{1}{2f(\frac{1}{2})}. \end{aligned}$$

if $f(\frac{1}{2}) < \frac{3}{2}$, *and otherwise the same as that given in Corollary 4.3.2.*

Proof. Corollary 4.3.2 shows that $s_1^* < 0$ and $s_2^* > 1$ if $f(\frac{1}{2}) < 3/2$. Then, firm 1 and firm 2 will locate at the the left side and the right side out of the unit residential area (line), respectively. Moreover, to the right side of s_1^* the profit of firm 1 is down sloping while to the left side of s_2^* the profit of firm 2 is up sloping. Therefore, with the location restrictions by which firms 1 and 2 have to locate inside the market, they will end up by locating at the left end and the right end of the market, respectively. Consequently, the two firms maximally differentiate their products. The equilibrium configurations then follow directly from substituting $s_1^* = 0, s_2^* = 1$, and $\xi^* = F(\xi^*) = \frac{1}{2}$ into equations (4.3.4)-(4.3.7).

If $f(\frac{1}{2}) \geq 3/2$, however, we have that $s_1^* \geq 0$ and $s_2^* \leq 1$, and then the necessary condition of Corollary 4.3.2 becomes also sufficient. Thus, the given outcome becomes the equilibrium configurations. The two firms then differentiate their products at the degree of $s_2^* - s_1^* = \frac{3}{2f(1/2)}$.

□

At the end of this section, we further restrict our attention to consider a situation that not only consumers are distributed symmetrically around the market centre, but also firms commit themselves to symmetric locations. This commitment of firms to symmetric locations may be imposed by zone regulations. It may also be interpreted as cooperation or collusion between the two firms because under symmetric consumer distributions the commitment of firms to symmetric locations guarantees them equal profits. In this case, the following proposition is derived.

Proposition 4.3.2 *Let the consumer density function $f(.)$ be symmetric, and two firms commit to symmetric locations. Then, under Assumption 4.2.1 there exists a unique subgame perfect equilibrium of the inside location game, which exhibits maximum product* *differentiation. The equilibrium prices and profits are*

$$
\begin{aligned}
p_1^* &= p_2^* = 1/f(1/2),\\
\pi_1^* &= \pi_2^* = 1/(2f(1/2)).
\end{aligned}
$$

Proof. Given that the consumers' distribution density function is symmetric and that the two firms commit to symmetric locations, we have from Lemma 4.3.1 that price competition at the second stage of the game results in that $\xi^* = 1/2$, $p_1^*(s_1, s_2) = p_2^*(s_1, s_2) = (s_2 - s_1)/f(1/2)$, and $\pi_1^*(s_1, s_2) = \pi_2^*(s_1, s_2) = (s_2 - s_1)/(2f(1/2))$. Differentiating the two firms' profits yields that $\partial\pi_1^*(s_1, s_2)/\partial s_1 = -1/(2f(1/2)) < 0$ and $\partial\pi_2^*(s_1, s_2)/\partial s_2 = 1/(2f(1/2)) > 0$. Therefore, at the first stage of the game, location competition leads firms 1 and 2 to choose the locations at $s_1^* = 0$ and $s_2^* = 1$, respectively. The consequent equilibrium levels of prices and profits follow directly from substituting s_1^* and s_2^* into $p_1^*(s_1, s_2), p_2^*(s_1, s_2), \pi_1^*(s_1, s_2)$ and $\pi_2^*(s_1, s_2)$ in equations (4.3.4), (4.3.5), (4.3.6) and (4.3.7) consequently.

□

At this stage, the difference arising from the firms' precommitment to symmetric locations becomes clear. Proposition 4.3.1 and Proposition 4.3.2 show that when consumers are distributed symmetrically and the consumer distribution density at 1/2, $f(\frac{1}{2})$, is lower than 3/2, maximum product differentiation prevails no matter whether the two firms commit to symmetric locations or not. Moreover, precommitment to symmetric locations changes neither the equilibrium configurations nor the social welfare.

If consumers are distributed around the market centre with a sufficiently high concentration, or if $f(\frac{1}{2}) > 3/2$, however, differences arise. Then, under the commitment to symmetric locations two firms' profits will be higher while consumer surplus is lower because of the increased prices and longer transportation (and thus higher transportation costs). Consequently, social welfare remains ambiguous. In summary, suppose that the firms may choose between precommitment and non-precommitment to symmetric locations, they will choose precommitment to symmetric locations if consumers are sufficiently concentrated around the market centre. Otherwise, no difference can be made by precommitment to symmetric locations. Moreover, in the former case consumer surplus is lower and social welfare is ambiguous

Thus far, our analysis of the inside location game shows that the concentration of consumer distributions effects product differentiation. The higher the concentration, the higher the market retention force and the lower the degree of the product differentiation.

This effect is observed for a class of specialized consumer distributions - symmetric consumer distributions. Moreover, this observation is quite intuitive. Locating at a area where consumers are highly concentrated a firm increases its market share but may also decreases its price because of the increased intensity of price competition; locating apart a firm may mitigate the intensity of the price competition and increases its price, but may also decrease its market share. Decreased product differentiation is observed when consumers are highly concentrated around the market center and market retention force dominates price competition force.

Having examined the effect of concentration of consumer distribution on product differentiation for the inside location game case, we now turn to the outside location game case to continue our discussion of the effect.

4.4 The outside location game

Let us now turn to the outside location game to examine the effect of consumer concentration on the degree of product differentiation. For this purpose, we may use Gabszewicz and Thisse (1986) as a benchmark, and keep all assumptions unchanged except substituting the concentrated consumer distributions for their uniform consumer distributions. Following backwards induction analysis procedure, we focus first on the second stage of price competition.

4.4.1 Price competition

To recall Gabszewicz and Thisse (1986), we have that in the outside location game, two firms choose their locations outside of the residential area $[0,1]$, that is, $1 \leq s_1 \leq s_2 < +\infty$. Transportation costs are linear-quadratic, implying that the total price a consumer residing at $x \in [0,1]$ has to pay equals $p_i + c(s_i - x) + d(s_i - x)^2$ if he buys from firm i, $i = 1, 2$. The marginal consumer is then defined as

$$\xi(s_1, s_2, p_1, p_2) = \frac{p_2 - p_1 + c(s_2 - s_1) + d(s_2^2 - s_1^2)}{2d(s_2 - s_1)}. \tag{4.4.1}$$

Given this marginal consumer's location and the assumption that the consumer's reservation price is infinite, firms 1 and 2 then share the market by $D_1 = F(\xi(s_1, s_2, p_1, p_2))$ and $D_2 = (1 - F(\xi(s_1, s_2, p_1, p_2)))$, respectively. Their consequent profits are thus represented by the same function forms as that given in (4.3.2) and (4.3.3).

As a corollary, the following lemma is derived directly from Caplin and Nalebuff (1991).

Lemma 4.4.1 *Under Assumption 4.2.1 there exists a unique equilibrium of price competition in pure strategies for any given location pair* (s_1, s_2)*,* s_1 *for firm 1 and* s_2 *for firm 2, with* $1 \le s_1 \le s_2 < +\infty$*. The equilibrium prices and profits are as follows*

$$p_1^*(s_1, s_2) = 2d(s_2 - s_1)F(\xi^*(s_1, s_2))/f(\xi^*(s_1, s_2)), \tag{4.4.2}$$

$$p_2^*(s_1, s_2) = 2d(s_2 - s_1)[1 - F(\xi^*(s_1, s_2))]/f(\xi^*(s_1, s_2)); \tag{4.4.3}$$

$$\pi_1^*(s_1, s_2) = 2d(s_2 - s_1)F^2(\xi^*(s_1, s_2))/f(\xi^*(s_1, s_2)), \tag{4.4.4}$$

$$\pi_2^*(s_1, s_2) = 2d(s_2 - s_1)[1 - F(\xi^*(s_1, s_2))]^2/f(\xi^*(s_1, s_2)). \tag{4.4.5}$$

where $\xi^*(s_1, s_2) = \xi^*(s_1, s_2, p_1^*(s_1, s_2), p_2^*(s_1, s_2))$*.*

Proof. First, under Assumption 4.2.1 Caplin and Nalebuff (1991) applies directly to guarantee the existence and uniqueness of the price equilibrium. Then, using the first order condition we may calculate the equilibrium configurations as follows

$$\frac{\partial \pi_1}{\partial p_1} = F(\xi) - \tfrac{p_1 f(\xi)}{2d(s_2 - s_1)} = 0, \tag{4.4.6}$$

$$\frac{\partial \pi_2}{\partial p_2} = 1 - F(\xi) - \tfrac{p_2 f(\xi)}{2d(s_2 - s_1)} = 0. \tag{4.4.7}$$

These two equations together with equations (4.3.2) and (4.3.3) lead to the equilibrium configurations.

□

At price equilibrium, the marginal consumer's location is specified as follows. Subtracting (4.4.2) from (4.4.3) yields the expression of $p_2^*(s_1, s_2) - p_1^*(s_1, s_2)$. Then, substituting this expression in (4.4.1) leads to the marginal consumer's location ξ^* defined as

$$\xi^*(s_1, s_2) = \frac{c}{2d} + \frac{1}{2}(s_1 + s_2) + \frac{1 - 2F(\xi^*(s_1, s_2))}{f(\xi^*(s_1, s_2))}. \tag{4.4.8}$$

Moreover, differentiating $\xi^*(s_1, s_2)$ in (4.4.8) with respect to s_1 and s_2 yields a property that is the same as that given in Lemma 4.3.2. Having derived the equilibrium configurations of the price competition, we are then in a position to consider the location stage of the game.

4.4.2 Location competition

First of all, we show that in the outside location game the two firms are asymmetric. That is, given our assumption on the two firms' locations, firm 1 earns a higher profit than firm 2. This property holds for quite general transportation cost functions as shown in the following lemma.

Lemma 4.4.2 *Let the transportation cost function $c(.)$ in the outside location game be differentiable and increasing, and suppose further that $s_1 < s_2$. Then, $\pi_1^*(s_1, s_2) > \pi_2^*(s_1, s_2)$.*

Proof. By setting up $p_1 = c(s_2 - 1) - c(s_1 - 1) - \epsilon$ for arbitrarily small $\epsilon > 0$, it is clear that firm 1 guarantees itself a strictly positive profit.

Let us then consider an equilibrium where only firm 1 is active, that is, $\pi_2^*(s_1, s_2) = 0$. In this case, Lemma 4.4.1 holds trivially. We may thus restrict ourselves to equilibria where both firms are active. Given that the indifferent consumer resides at ξ^* it must hold that $p_1 + c(s_1 - \xi^*) = p_2 + c(s_2 - \xi^*)$. The resulting profits of firms 1 and 2 are $\pi_1^* = p_1 F(\xi^*)$, $\pi_2^* = p_2(1 - F(\xi^*))$. Differentiating π_1^* and π_2^* with respect to p_1 and p_2, respectively, yields $p_1 = \frac{F(\xi^*)}{F'(\xi^*)}[c'(s_2 - \xi^*) - c'(s_1 - \xi^*)]$, and $p_2 = \frac{1-F(\xi^*)}{F'(\xi^*)}[c'(s_2 - \xi^*) - c'(s_1 - \xi^*)]$, because $p_1 + c(s_1 - \xi^*) = p_2 + c(s_2 - \xi^*)$. Consequently, we have that $\pi_1^*(s_1, s_2) - \pi_2^*(s_1, s_2) = p_1 F(\xi^*) - p_2(1 - F(\xi^*)) = \frac{F(\xi^*)^2 - (1-F(\xi^*))^2}{F'(\xi^*)}[c'(s_2 - \xi^*) - c'(s_1 - \xi^*)] = \frac{2F(\xi^*)-1}{F'(\xi^*)}[c'(s_2 - \xi^*) - c'(s_1 - \xi^*)] = p_1 - p_2 = c(s_2 - \xi^*) - c(s_1 - \xi^*) > 0.$

□

This lemma shows an asymmetry between firm 1 and firm 2. The location restrictions that $1 \leq s_1 \leq s_2 < +\infty$ provide firm 1 with an advantage over firm 2. This advantage arises because of firm 1 locating closer to the consumers than firm 2. It looks like that firm 1 provides a higher quality product than firm 2. Therefore, the restriction has the interpretation that firm 1 is a quality (or technology) leader and firm 2 is a quality (or technology) follower.

Solving equations (4.3.11) and (4.4.8) provides us the following necessary condition that a subgame perfect equilibrium, if it exists, should satisfy.

Lemma 4.4.3 *Under Assumption 4.2.1, a subgame perfect equilibrium $(s_1^*, s_2^*, p_1^*, p_2^*)$ of the location-then-price game without location restriction, if it exists, must satisfy*

$$s_1^* = \xi^* - \frac{(1-F(\xi^*))(2-F(\xi^*))}{f(\xi^*)} - \frac{c}{2d},$$

$$\begin{aligned} s_2^* &= \xi^* + \tfrac{F(\xi^*)(1+F(\xi^*))}{f(\xi^*)} - \tfrac{c}{2d}, \\ p_1^* &= \tfrac{4dF(\xi^*)(1-F(\xi^*)+F^2(\xi^*))}{f^2(\xi^*)}, \\ p_2^* &= \tfrac{4d(1-F(\xi^*))(1-F(\xi^*)+F^2(\xi^*))}{f^2(\xi^*)}, \end{aligned}$$

and yield profits

$$\begin{aligned} \pi_1^* &= \tfrac{4dF^2(\xi^*)(1-F(\xi^*)+F^2(\xi^*))}{f^2(\xi^*)}, \\ \pi_2^* &= \tfrac{4d(1-F(\xi^*))^2(1-F(\xi^*)+F^2(\xi^*))}{f^2(\xi^*)}, \end{aligned}$$

where ξ^* is the solution to (4.3.14).

Proof. Lemmas 4.3.1 and 4.4.1 show that equation (4.3.11) holds also under the conditions of Lemma 4.4.3. Solving equations (4.3.11) and (4.4.8) yields s_1^* and s_2^*. Substituting the expression of $s_2^* - s_1^*$ in the equation (4.3.11) for $s_2 - s_1$ in (4.4.2)-(4.4.5) yields p_1^*, p_2^*, π_1^* and π_2^*.

□

Clearly, Lemma 4.4.3 is not a sufficient condition of a subgame perfect equilibrium of the outside location game because $s_1^* < 1$. To derive the sufficient condition, a further assumption is introduced, under which the result of Goeree and Ramer (1994) applies directly to guarantee the uniqueness of the maximum extreme of the firms' profit functions.

Assumption 4.4.1 *The consumer density function and the consumer cumulative function satisfy*

$$((\frac{2F(x)-1}{f(x)})' + 1)(\frac{f(x)}{F^2(x)})'' - (\frac{f(x)}{F^2(x)})'((\frac{2F(x)-1}{f(x)})' + 1)' > 0,$$

for all $x \in [0,1]$, and a similar condition with f/F^2 replaced by $f/F(1-F)^2$ holds.

□

Following Assumption 4.4.1 is a sufficient condition on the existence and uniqueness of a subgame perfect equilibrium of the outside location game, derived as follows.

Proposition 4.4.1 *Under Assumptions 4.2.1 and 4.4.1, there exists a unique subgame perfect equilibrium $(s_1^*, s_2^*, p_1^*, p_2^*)$ of the outside location game, which satisfies*

$$s_1^* = 1, \tag{4.4.9}$$

$$s_2^* = 1 + \frac{1-F(\xi^*)}{f(\xi^*)} \cdot \frac{6f^2(\xi^*)+2(1-2F(\xi^*))f'(\xi^*)}{2f^2(\xi^*)+(1-F(\xi^*))f'(\xi^*)}, \tag{4.4.10}$$

$$p_1^* = \frac{4dF(\xi^*)(1-F(\xi^*))}{f^2(\xi^*)} \cdot \frac{3f^2(\xi^*)+(1-2F(\xi^*))f'(\xi^*)}{2f^2(\xi^*)+(1-F(\xi^*)f'(\xi^*)}, \tag{4.4.11}$$

$$p_2^* = \frac{4d(1-F(\xi^*))^2}{f^2(\xi^*)} \cdot \frac{3f^2(\xi^*)+(1-2F(\xi^*))f'(\xi^*)}{2f^2(\xi^*)+(1-F(\xi^*)f'(\xi^*)}, \tag{4.4.12}$$

and yields profits

$$\pi_1^* = \frac{4dF^2(\xi^*)(1-F(\xi^*))}{f^2(\xi^*)} \cdot \frac{3f^2(\xi^*)+(1-2F(\xi^*))f'(\xi^*)}{2f^2(\xi^*)+(1-F(\xi^*)f'(\xi^*)},$$

$$\pi_2^* = \frac{4d(1-F(\xi^*))^3}{f^2(\xi^*)} \cdot \frac{3f^2(\xi^*)+(1-2F(\xi^*))f'(\xi^*)}{2f^2(\xi^*)+(1-F(\xi^*)f'(\xi^*)},$$

where ξ^* *is determined by*

$$\xi^* = 1 + \frac{1-2F(\xi^*)}{f(\xi^*)} + \frac{1-F(\xi^*)}{f(\xi^*)} \cdot \frac{3f^2(\xi^*)+(1-2F(\xi^*))f'(\xi^*)}{2f^2(\xi^*)+(1-F(\xi^*)f'(\xi^*)} + \frac{c}{2d}.$$

Proof. Under Assumption 4.2.1 Lemma 4.4.3 shows that $s_1^* < 1$. Moreover, Assumption 4.4.1 guarantees that the profit function of firm 1 has only one peak. Therefore, at the right side of the location corresponding to this peak point the profit function of firm 1 is always downward sloping. Thus, $s_1^* = 1$ maximizes firm 1's profit in the outside location game under the restriction $s_1 \geq 1$.

The profit maximization of firm 2 yields a equation which is equivalent to equation (4.3.13). Therefore, substituting $s_1^* = 1$ for s_1^* in equation (4.3.13) yields s_2^*, which gives ξ^* when being substituted into (4.4.8) together with $s_1^* = 1$. Finally, substituting $s_2^* - s_1^*$ into (4.4.2)-(4.4.5) yields p_1^*, p_2^*, π_1^*, and π_2^*.

□

This proposition provides a unique subgame perfect equilibrium of the outside location game, in which firm 1 locates at the left end of the location space or $s_1^* = 1$ while firm 2 chooses a location somewhere on the right side of firm 1. Thus, the two firms differentiate their products with a degree of $s_2^* - s_1^*$. To see the effect of consumer concentration on the degree of product differentiation, we may specify further the consumer density function. In the next section, this effect is discussed through an example in which a concrete consumer density function is defined.

4.4.3 Triangular consumer distributions

In this section, we follow Gabszewicz and Thisse's (1986) model, but substitute a triangular consumer distribution for their uniform consumer distribution. This substitution may provide us a clear observation of the effects of consumer concentrations around the market centre on the degree of product differentiation.

More precisely, we assume that consumers are distributed with a density function $f(x) = 2 - |2 - 4x|$ over the interval [0, 1]. Then, the density function has the following expression

$$f(x) = \begin{cases} 4x & \text{if } x \leq \frac{1}{2} \\ 4 - 4x & \text{otherwise,} \end{cases}$$

and its cumulative function holds as

$$F(x) = \begin{cases} 2x^2 & \text{if } x \leq \frac{1}{2} \\ -2x^2 + 4x - 1 & \text{otherwise.} \end{cases}$$

Given this distribution of consumers, we claim that the equilibrium levels of locations and prices of the two firms hold as follows.

Proposition 4.4.2 *Let the consumer density function $f(x) = 2-|2-4x|$ for all $x \in [0,1]$. Then, there exists a unique subgame perfect equilibrium, in which the following equilibrium configurations hold*

$$\begin{aligned} s_1^* &= 1, \\ s_2^* &= 1 + \tfrac{c}{8d} + \tfrac{1}{8}\sqrt{64 + \tfrac{9c^2}{d^2}}, \\ p_1^* &= \tfrac{7d}{4} + \tfrac{9c^2}{64d} - \tfrac{5c}{64}\sqrt{64 + \tfrac{9c^2}{d^2}}, \\ p_2^* &= \tfrac{d}{4} + \tfrac{3d^2}{128d} - \tfrac{c}{128}\sqrt{64 + \tfrac{9c^2}{d^2}}. \end{aligned}$$

Proof. Because $f(.)$ is not differentiable at $x = \frac{1}{2}$, Assumption 4.2.1 does not hold. Therefore, Proposition 4.4.1 does not apply. We may, however, seek for an alternative way of the proof through selection and elimination.

First, we prove that $\xi^*(s_1, s_2) \notin [0, 1/2]$. Otherwise, from equation (4.4.8), $s_2 = 2\xi^* - c/d - s_1 - \frac{2(1-2F(\xi^*))}{f(\xi^*)} \leq 1 - c/d - 1 - \frac{2(1-4(\xi^*)^2)}{4(1-\xi^*)} < 0$, contradicting with the restriction $1 \leq s_2$.

Secondly, we solve ξ^* when no restriction is imposed on locations. From the fact that $\xi^* \neq \frac{1}{2}$, we have that f is differentiable at ξ^*. Solving (4.3.14), we get the following values for ξ^*: 0, $1/\sqrt{6}$, $1-1/\sqrt{6}$, 1. But at any location equilibrium, $\xi^* = 0$ or 1 can not happen since otherwise one firm would be driven out of business.

Finally, we focus on the outside location game. Then, $\xi^* = 1/\sqrt{6} \notin (\frac{1}{2}, 1]$ can also not happen. So we are left with $\xi^* = 1 - 1/\sqrt{6}$. Substituting ξ^* into equations (4.3.11) and (4.4.8), and then solving these equations yield that $s_1^{'} = 1 - 5/(3\sqrt{6}) - c/(2d) < 1$ and $s_2^{'} = 1 + 2/(3\sqrt{6}) - c/(2d)$. Again $s_1^{'}$ and $s_2^{'}$ can not hold as equilibrium locations in the outside location game. But it is straightforward that $s_1^* = 1$ will be the optimal location of firm 1 for any given location of firm 2 in the outside location game. Then we are left with solving the optimizing location of firm 2 given $s_1^* = 1$.

Since $\xi^*(1, s_2) \notin [0, 1/2)$, we have $f(x) = 4-4x$ and $F(x) = -2x^2+4x-1$. Substituting $f(x)$ and $F(x)$ into the equation for s_2^* and ξ^* in (4.4.7) and (4.4.10), we obtain

$$\xi^* = 1 - \frac{2}{\frac{3c}{d} + \sqrt{64 + \frac{9c^2}{d^2}}} \text{ and } s_2^* = 1 + \frac{c}{8d} + \frac{1}{8}\sqrt{64 + \frac{9c^2}{d^2}}.$$

Subsequently, p_1^* and p_2^* follow from substituting s_1^* and s_2^* into (4.4.11) and (4.4.12), respectively.

□

This result shows that when the consumer distribution density takes the above given triangular form, there exhibits a differentiation between the two firms' products with a degree of $s_2^* - s_1^* = \frac{c}{8d} + \frac{1}{8}\sqrt{64 + \frac{9c^2}{d^2}}$. When consumers are distributed uniformly, however, direct calculation from Proposition 4.4.1 leads to a unique subgame perfect equilibrium, in which firm 1 and firm 2 locate at 1 and $1 + 2/3 - c/(3d)$, respectively. Thus, the two firms exhibit a degree of product differentiation at $2/3 - c/(3d)$. Moreover, the uniqueness of the equilibrium requires that $\xi^* < 1$ holds, for which $c < 2d$ must be assumed. Otherwise, if $c \geq 2d$, then $\xi^* \geq 1$, which means that firm 2 stays out of the market. This is exactly the result given in Gabszewicz and Thisse (1986). Direct comparison between these degrees of product differentiation leads to the following corollary.

Corollary 4.4.1 *In a outside location game with the linear-quadratic transportation cost and the assumption that $c < 2d$, the two firms will increase their product differentiation if the consumers' distribution changes from the uniform density to the triangular one.*

□

This corollary shows that when consumers are sufficiently concentrated around the market center, the firms' location behaviour in the outside location game is sharply different from that in the inside location game. While product differentiation is decreased in the latter case, it is increased in the former case. The difference arises from the asymmetry between the two firms in the outside location game. The intuition is as follows. Standard results of a vertical product differentiation model show that the lower quality product firm wants more product differentiation, since this relaxes price competition and increases profits (see Tirole, 1988). When consumers are sufficiently concentrated around the market center, however, at the same prices and locations firm 1's market share is increased. This increased market share of firm 1 provides firm 1 a further advantage over firm 2, and forces firm 2 to locate further apart to relax price competition. As a result, product differentiation is increased. Although it is impossible to calculate for every case, we believe that the result remains in general true when consumer distribution changes from a uniform density to a non-uniform density but concentrated around the market centre.

4.5 Conclusion

Relaxing the assumption of a uniform consumer distribution by a log-concave distribution density function provides a more realistic model, but creates a market retention force in the inside location game or increases the asymmetry between firms in the outside location game. Firms then try to balance the trade-off in the inside location game between locating apart to relax price competition and moving closer to increase market share. As a result, when consumers are not too concentrated around the market centre, the price competition force dominates the market retention force, and firms will differentiate their products maximally. When consumers are sufficiently concentrated over a certain level, the market retention force starts to dominate the price competition force, and the firms gradually move toward the inside of the market along with increasing concentration of consumer distribution around the market centre. An exception is the case with *ex ante* commitment to symmetric locations. In that case, increasing concentration of consumer distributions around the market centre does not affect the locations of both firms, and the two firms always maximally differentiate their products by locating at the two extremes.

The opposite behaviour is observed in the outside location game and shown in the triangular example. Although it is impossible to calculate for every case of the outside location game, we believe that the result remains generally true when consumer distribution changes from uniform to non-uniform but concentrated around the market centre. This is because the consumer concentration around the market center increases the market shares of the firms that locate closer to consumers while it decreases the market shares of the other firms. Then, the asymmetry between firms is increased further. As a result, the firms with inferior positions want to move apart further from the others, and product differentiation is thus increased.

The work may be extended by considering an alternative vertical product differentiation model as, e.g., Shaked and Sutton (1982). This is because the alternative model captures quality competition more precisely whereas consumers are distributed by their tastes or incomes. Intuitively, consumers are concentrately distributed by their incomes (being concentrated around the average income is the most plausible example). Thus, the extension may provide a more realistic vertical product differentiation model.

References

CAPLIN, A. AND B., NALEBUFF, 1991, "Aggregation and Imperfect Competition: On the Existence of Equilibrium", *Econometrica*, 59, 25-59.

D'ASPREMONT, C., J.J., GABSZEWICZ AND J.-F., THISSE, 1979, "On Hotelling's stability in competition", *Econometrica*, 47, 1145-1150.

GABSZEWICZ, J.J. AND J.-F., THISSE, 1986, "On the Nature of Competition with Differentiated Products", *The Economic Journal*, 96, 160-172.

GOEREE, J. AND R., RAMER, 1994, "Exact Solutions of Location Games", TI94-70, University of Amsterdam, Amsterdam.

HAN, J.X. AND H., WEBERS, 1996, "A Comment on Shaked and Sutton's Model of Vertical Product Differentiation", CentER DP, No. 9666, Tilburg University, Tilburg.

HOTELLING, H., 1929, "Stability in Competition", *Economic Journal*, 39, 41-57.

NEVEN, D. J., 1986, "On Hotelling's Competition with Non-Uniform Customer Distributions", *Economics Letters*, 21, 121-126.

SHAKED, A. AND J., SUTTON, 1982, "Relaxing Price Competition through Product Differentiation", *Review of Economic Studies*, XLIX, 3-13.

TABUCHI, T. AND J.-F., THISSE, 1995, "Asymmetric Equilibria in Spatial Competition", *International Journal of Industrial Organization*, 13, 213-227.

Chapter 5

Standardization and protection under international competition

5.1 Introduction

Several industries are global in scope. The most significant firms in personal computers, telecommunications, VCRs, cars, or numerically controlled machine tools compete worldwide. In these markets, different government standards may be imposed. Moreover, many government-imposed standards seem to intend to protect local producers from foreign competition. This "hidden" protectionism is problematic with regards to the General Agreement on Tariffs and Trade as well as to ISO's efforts to harmonize standards across borders. Given the importance of these policy issues it is surprising that the theoretical literature on standardization has focused almost completely on closed economies.

Extending the literature to an international environment involves two main modifications in the model. First, there are now *domestic* and *foreign* firms. The crucial difference here is that the profits of foreign-owned firms do not or at least do not completely contribute to the home country's surplus so that the optimal standardization policies of the home country might well differ from what it would be in a closed economy. Second, some of the markets in which foreign and domestic firms compete might be served through exports. This opens the door to a strategic use of trade-policy instruments such as tariffs, quotas, export taxes, or subsidies. As noted by Matutes and Regibeau (1996), however, one hardly finds any study on the consequences of these two departures from the traditional assumptions. The only exception, to the best of our knowledge, might be Jeanneret and Verdier (1996). In that paper, the impact of trade policies on the standardization choices of the firms in an international environment is studied in the absence of network externalities. But, the limit of that study is that the perceived qualities of both the firms' products and the perceived quality gap between them are exogenously decided.

In this chapter, the vertical product differentiation framework is extended to deal with trade policy issues under international competition. In particular, trade policies may effect - and be effected by - the standardization choices of firms, which decides then on the standardization choices of firms and optimal trade policies of the government. These will be the focus of this chapter.

A vertically differentiated duopoly is studied. The domestic firm is an incumbent and quality follower, while the foreign firm is an entrant and quality leader. The perceived qualities of and the perceived quality gap between both firms' products are endogenized. The two firms produce system goods instead of single goods. A system good consists of a hardware and a software, any component of which alone is not useful. Under standardization, a hardware component from one firm can be used together with a software component from any of the other firms in order to produce a useful system good. Furthermore, in our considerations the two firms play a Stackelberg game in price competition instead of a Bertrand game. Since the domestic firm is an incumbent, it enjoys the first-mover advantage. As an entrant, the foreign firm is a follower of the price competition game. We shall look at first the effect of trade policies on the standardization choices of firms. Then, we consider the incentives of governments in the process of setting up international standards.

More precisely, we consider a situation where a domestic firm faces competition from a foreign firm when the home country changes its closed economy into an open economy. The foreign firm is the production technology leader and entrant, while the domestic firm is the production technology follower and incumbent. Each producer produces not only hardware but also software. Examples include durable equipment and repair service (the equipment is hardware, the repair service is software) and personal computers and softwares (computers are hardware, spreadsheets, word processors, databases, communication software, etc., are softwares). The situation might be envisioned by considering a computer, washing machine, or television industry, in which a developing country opens its door to the outside world, particularly, to a developed country. The domestic firm has the disadvantage of producing a lower quality product. It has also, however, some advantages, such as being protected by the government's tariffs or subsidies, and the first-mover advantage of being an incumbent. We examine the trade-off between these advantages and disadvantages. The impact of trade policies on standardization choices of firms and optimal trade policies are then analysed.

Katz and Shapiro (1994) argue that for system goods that are compatible, the locus of competition shifts from an overall package to specific costs and performance characteristics of each component individually. This general principle implies that if one firm has a distinctly superior overall package, including product offering, installed base and reputation, that firm is likely to prefer non-standardization and may in fact spend resources to block standardization. If, however, each firm has a distinctly superior component, both firms may prefer standardization and may spend resources to achieve it. Similarly, as we will demonstrate, to the extent that the quality differences create one type of asymmetry between firms, and trade policies and the first-mover advantage create another type of asymmetry, it is conjectured that standardization might be achieved.

We show that trade liberalization (which means that the tariff level goes to zero) is associated with standardization of the system goods while protectionism (which means that the tariff level goes to infinity) may lead to non-standardization, when the consumers' taste parameters are independent. When the consumers' taste parameters are identical, however, the standardization choices of firms are independent of the government's trade policies. We also show that neither domestic surplus nor optimal trade policies will be changed by the government's precommitment to a given tariff level, and that standardization is always implemented by the government. This result is based on the assumption of explicit agreement on standardization between firms, i.e., standardization can only be achieved when both firms agree on it.

The intuition of the results is as follows. First of all, from a consumer's point of view, the foreign firm's hardware and software advantages augment one another. When consumers' taste parameters are independent, a consumer's valuation of quality upgrades in hardware and software is uncorrelated, and the value-augmenting effect of hardware and software is more diffuse. This tends to overall decrease the foreign firm's ability to distinguish his product under non-standardization; as a result, its market power and the price decline. Under standardization, however, the hardware and software markets are completely separated, and the foreign firm can differentiate its hardware and software from that of the domestic firm without being effected by consumers' tastes of hardware and software. Thus, product differentiation is increased under standardization when the consumers' taste parameters are independent. The standardization choices of the two firms, however, depend on the overall advantages they may enjoy. For the foreign firm, the advantage enjoyed by acting as a quality leader is balanced by the cost disadvantage created by the government's tariff and by acting as an entrant. The foreign firm then prefers standardization. The reversal is true for the domestic firm. The advantage enjoyed by the foreign firm is the disadvantage of the domestic firm, and vice versa. Furthermore, the advantage and disadvantages of the domestic firm will be balanced if the tariff level imposed by the government is sufficiently low, and standardization is therefore also preferred. Otherwise, the domestic firm will enjoy overall advantages over the foreign firm because of the heavily government-imposed tariff on the foreign firm, and thus the strong government protection from foreign competition. The domestic firm then prefers non-standardization. Because standardization can not survive unless both firms agree on it, non-standardization will be the choice of the two firms if the government-imposed tariff is sufficiently high. This observation is consistent to the finding derived from Katz and Shapiro (1994).

When consumers' taste parameters are identical, the hardware and software of a system good are correlated, and the foreign firm can differentiate its system good from that of the domestic firm under non-standardization. In this case, standardization can not increase further the product differentiation, neither does the government's trade policies.

The remainder of the chapter is organized as follows. First, a model is presented in Section 5.2 to formalize the situation described above. Then, equilibrium configurations under non-standardization and standardization are derived in Sections 5.3 and 5.4, respectively. In Section 5.5, we compare the equilibrium prices and profits derived from the non-standardization and standardization cases to discuss the impacts of trade policies on the standardization choices of firms. Finally, the reversed impacts are discussed by distinguishing between the government as a leader and as a follower in Section 5.6 to decide on optimal trade policies. Section 5.7 concludes.

5.2 The model

Consider a durable-goods industry in a country with a domestic producer (firm 1), the incumbent, facing competition from a foreign producer (firm 2), the entrant. Let each producer manufacture both hardware and software, where firm 2 produces hardware and software of "superior" quality. Assume that the unit production costs of both firms are zero.[1] The government of the country may impose a tariff of level t, with $t > 0$, on each unit of the system good sold or exported by firm 2; the tariffs are imposed on the hardware and software of the foreign firm's system good individually according to their quality shares in the system good. Both producers' decision making processes evolve a three-stage game. In the first stage, firms decide on standardization simultaneously. If the two firms agree on standardization or make their products compatible, a hardware from one firm may be then used together with a software from the rival in order to produce a useful system good. In the remaining two stages, the two firms play a Stackelberg

[1] Assuming different unit production costs does not change the results qualitatively but complicates the analysis and the presentation.

price game. In the second stage, the domestic firm optimizes its prices in anticipating its pricing effect on the foreign firm's pricing behaviour. In the third stage, the foreign firm decides on pricing given the domestic firm's pricing. The game is solved through backwards induction to yield a subgame perfect equilibrium.

We consider a type of standardization mechanism where coordination on standards is obtained through an explicit agreement between firms. This standardization mechanism has been widely observed empirically (Nicolas, 1988). A typical example is the International Organization for Standardization (ISO). This organization attempts to harmonize standards internationally, and is responsible, for instance, for the Open Systems Interconnection reference model in mainframe computers.

To derive positive utility, a consumer must get one unit of both hardware and software; owning more than one unit of either does not increase utility. For convenience, we assume that each consumer purchases one unit of both hardware and software.

Let subscript (i,j) designate a system good, with i denoting hardware of firm i and j software of firm j. The numbers P_i and p_j represent the prices of hardware i of firm i and software j of firm j, respectively. Each consumer has the same reservation price, V_0, for the worst available system. Let Q and q represent the incremental value of the superior hardware and software to the average consumer, respectively. We assume that $Q > q$, that is, hardware is more valuable than software. Let k_Q and k_q be the consumer's taste parameters for the qualities of hardware and software, respectively; k_Q and k_q differ among consumers. Then, a consumer's utility derived from owning the system good (i,j) can be written as

$$U_{(i,j)} = Y + V_0 + I_i^h k_Q Q + I_j^s k_q q - P_i - p_j, \tag{5.2.1}$$

where
Y =personal endowment, assumed identical for all consumers,
$I_1^h = I_1^s = 0$, and $I_2^h = I_2^s = 1$.
This functional form is similar to the one used in Gabszewicz and Thisse (1979) and Einhorn (1992).

5.3 Equilibrium under non-standardization

To derive the equilibrium levels of prices and profits for the two firms under non-standardization, we may distinguish between the cases of identical and independent taste parameters.

Identical taste parameters. We assume, first, that an individual's taste parameters of hardware and software are identical, that is, $k_Q = k_q = k$. We suppose further that the taste parameter k is uniformly distributed with support $[0,2]$, with density 1/2. Given non-standardization, consumers can only choose between systems (1,1) and (2,2). Let K be the taste parameter value of the *crossover consumer*, the one who is indifferent between the systems (1,1) and (2,2) (that is, $U_{(1,1)} = U_{(2,2)}$). From equation (5.2.1), it follows that

$$K = \frac{P_2 - P_1 + p_2 - p_1}{Q + q}.$$

Given the foreign firm 2's quality leadership in both hardware and software, consumers with a taste parameter k smaller (larger) than K select system (1,1) ((2,2)). Therefore, the market shares of the system goods (1,1) and (2,2) are $M_{(1,1)} = \frac{K}{2}$ and $M_{(2,2)} = 1 - \frac{K}{2}$, respectively.

Given that the unit production costs of both firms are zero, and that $t > 0$ represents the unit tariff cost of firm 2's system good, the profits π_1 of firm 1 and π_2 of firm 2 under non-standardization are

$$\begin{aligned}\pi_1 &= (P_1 + p_1)\frac{P_2 - P_1 + p_2 - p_1}{2(Q+q)},\\ \pi_2 &= (P_2 + p_2 - t)(1 - \frac{P_2 - P_1 + p_2 - p_1}{2(Q+q)}).\end{aligned}$$

Define $\overline{P_1} := P_1 + p_1$, $\overline{P_2} := P_2 + p_2$, and $\overline{Q} := Q + q$. Solving for the Stackelberg price game with firm 1 being the leader yields the equilibrium levels of prices and profits as follows

$$\overline{P}^{id}_{1ns} = \overline{Q} + \frac{t}{2}, \tag{5.3.1}$$

$$\overline{P}^{id}_{2ns} = \frac{3}{4}(2\overline{Q} + t), \tag{5.3.2}$$

$$\pi^{id}_{1ns} = \frac{1}{16\overline{Q}}(2\overline{Q} + t)^2, \tag{5.3.3}$$

$$\pi^{id}_{2ns} = \frac{1}{32\overline{Q}}(6\overline{Q} - t)^2, \tag{5.3.4}$$

at which the crossover consumer is given by

$$K = \frac{1}{2} + \frac{1}{4}\frac{t}{\overline{Q}}.$$

Given that k is uniformly distributed, we have that $\partial^2\pi_i/\partial^2\overline{P_i} < 0$, which guarantees a unique profit-maximum. In a shared Stackelberg price equilibrium at which both firms share the market, both market shares must be positive, which means that $P_2+p_2 > P_1+p_1$ and $M_{(2,2)} > 0$ must hold in a shared equilibrium. From (5.3.1)-(5.3.2), these inequalities hold if and only if $-2\overline{Q} < t < 6\overline{Q}$. Therefore, to ensure a shared equilibrium, this inequality must hold.

Independent taste parameters. Next, we consider the case that a consumer's taste parameters k_Q and k_q differ, and are independently and jointly uniformly distributed with support $[0,2]\times[0,2]$, with density $1/4$ and means $(1,1)$. The value for a consumer (k_Q, k_q) upgrading system good from (1,1) to (2,2) is $S = k_Q Q + k_q q$; S distributes with support $[0, 2(Q+q)]$, with mean $Q+q$, and cumulative distribution

$$G(S) = \begin{cases} S^2/[8qQ] & \text{if } S \leq 2q \\ [S-q]/[2Q] & \text{if } 2q \leq S \leq 2Q \\ 1-[2(Q+q)-S]^2/[8qQ] & \text{if } S \geq 2Q. \end{cases}$$

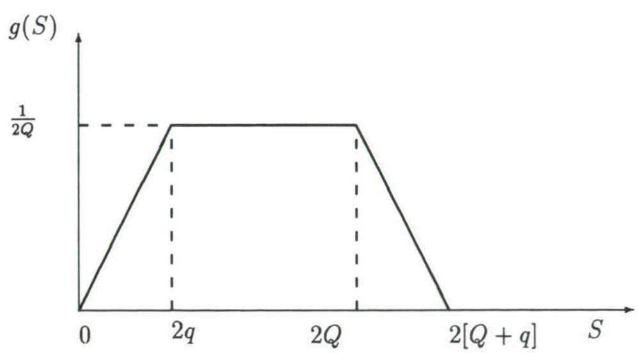


Figure 5.1 Density $g(S)$ for independent taste parameters.

Figure 5.1 illustrates the density $g(S) = G'(S)$ of S. To derive the equilibrium prices and the associate profits for both firms, we restrict ourselves to the intermediate range of $g(S)$, that is, $2q < S < 2Q$, $g(S) = 1/[2Q]$, and $G(S) = [S-q]/[2Q]$.
A consumer will prefer system (1,1) ((2,2)) if the quality differential is less (greater) than

the price differential. The crossover consumer is then

$$S = k_Q Q + k_q q = P_2 + p_2 - P_1 - p_1.$$

Therefore, under non-standardization, the market shares of the system good (i,i), $i = 1, 2$, are

$$\begin{aligned} M_{(1,1)} &= G(P_2 + p_2 - P_1 - p_1), \\ M_{(2,2)} &= 1 - G(P_2 + p_2 - P_1 - p_1). \end{aligned}$$

And profits are

$$\begin{aligned} \pi_1 &= (P_1 + p_1)\frac{P_2 + p_2 - P_1 - p_1 - q}{2Q}, \\ \pi_2 &= (P_2 + p_2 - t)(1 - \frac{P_2 + p_2 - P_1 - p_1 - q}{2Q}). \end{aligned}$$

Again, let $\overline{P_1} = P_1 + p_1$ and $\overline{P_2} = P_2 + p_2$. Solving for the Stackelberg price game with firm 1 being the leader yields equilibrium levels of prices and profits as follows

$$\overline{P}_{1ns}^{in} = Q + \frac{t}{2} - \frac{q}{2}, \tag{5.3.5}$$

$$\overline{P}_{2ns}^{in} = \frac{3}{2}Q + \frac{3}{4}t + \frac{1}{4}q, \tag{5.3.6}$$

$$\pi_{1ns}^{in} = \frac{1}{16Q}(2Q + t - q)^2, \tag{5.3.7}$$

$$\pi_{2ns}^{in} = \frac{1}{32Q}(6Q + q - t)^2, \tag{5.3.8}$$

at which the crossover consumer is given by

$$S = \frac{1}{2}Q + \frac{3}{4}q + \frac{1}{4}t.$$

To ensure a shared Stackelberg price equilibrium, both market shares must be positive, which means that $P_2 + p_2 > P_1 + p_1$ and $M_{(2,2)} > 0$ must be assumed to hold, or $-2Q - 3q < t < 6Q + q$ is required. To ensure that $2q < S < 2Q$, we require $-2Q + 5q < t < 6Q - 3q$. The second required inequality subsumes the first and the tariff restriction under identical taste parameters, and therefore must be assumed from now on.

Equilibria compared. Comparing (5.3.1)-(5.3.4) with (5.3.5)-(5.3.8), the composite system price $P_1 + p_1$ decreases by $\frac{3}{2}q$ while $P_2 + p_2$ decreases by $\frac{5}{4}q$ when consumers' taste parameters k_Q and k_q are independent of each other. In fact, producer 2's hardware and software advantages augment one another. If the parameters are independent, a consumer's valuation of quality upgrades in hardware and software are uncorrelated, and the value-augmenting effect of hardware and software is more diffuse. This tends to overall decrease producer 2's ability to distinguish his product; and as a result, its market power and equilibrium prices decline. Firm 1's equilibrium price declines more because of its first-mover advantage, that is, the effect of product differentiation on the first-mover advantage is negative: The more differentiation, the less first-mover advantage.

A consequence of this reduced product differentiation is the shrinking of the market. In the identical consumers' taste parameters case, the maximum tariff level for the market to hold both firms is $6(Q + q)$, while in the independent consumers' taste parameters case this maximum tariff level is reduced to $6Q + q$.

5.4 Equilibrium under standardization

Under standardization, a consumer's software and hardware choices are entirely independent of each other. Let J and L represent crossover points at which a consumer is indifferent between paying for a quality upgrade in software and hardware markets, respectively. It follows from equation (5.2.1) that

$$J = \frac{p_2 - p_1}{q}, L = \frac{P_2 - P_1}{Q}.$$

Consumers with $k_q < (>) J$ select software 1 (software 2); consumers with $k_Q < (>) L$ select hardware 1 (hardware 2).

Let n_i and N_i represent respective market shares of the software and the hardware manufactured by producer i, then we have that

$$
\begin{aligned}
n_1 &= \frac{J}{2}, n_2 = 1 - \frac{J}{2}; \\
N_1 &= \frac{L}{2}, N_2 = 1 - \frac{L}{2}.
\end{aligned}
$$

Given that the unit tariff cost imposed on firm 2 by the domestic government is t, and out of which $\frac{Q}{Q+q}t$ and $\frac{q}{Q+q}t$ are imposed on the hardware and the software of the system good of firm 2, respectively, we can derive the respective profits of firm 1 and firm 2 as

$$
\begin{aligned}
\pi_1 &= P_1 \frac{P_2 - P_1}{2Q} + p_1 \frac{p_2 - p_1}{2q}, \\
\pi_2 &= (P_2 - \frac{Q}{Q+q}t)(1 - \frac{P_2 - P_1}{2Q}) + (p_2 - \frac{q}{Q+q}t)(1 - \frac{p_2 - p_1}{2q}).
\end{aligned}
$$

Solving for the Stackelberg price game with firm 1 being the leader yields the equilibrium levels of prices and profits for the two firms as follows

$$
\begin{aligned}
p_{1s} &= q + \frac{q}{2\overline{Q}}t, P_{1s} = Q + \frac{Q}{2\overline{Q}}t, && (5.4.1) \\
p_{2s} &= \frac{3}{2}q + \frac{3q}{4\overline{Q}}t, P_{2s} = \frac{3}{2}Q + \frac{3Q}{4\overline{Q}}t, && (5.4.2) \\
\pi_{1s} &= \frac{1}{16\overline{Q}}(2\overline{Q} + t)^2, && (5.4.3) \\
\pi_{2s} &= \frac{1}{32\overline{Q}}(6\overline{Q} - t)^2, && (5.4.4)
\end{aligned}
$$

at which $J = L = \frac{1}{2} + \frac{1}{4}\frac{t}{\overline{Q}}$.

Thus far, we have derived the equilibrium configurations for both firms under their standardization and non-standardization choices, respectively. We are then in a position to perform a comparative statics analysis of these choices.

5.5 Comparison of equilibrium prices and profits

Comparing (5.4.1)-(5.4.4) with (5.3.1)-(5.3.4), we find that the standardization choices of firms have no influence on the prices and profits of firms' system goods when consumers' tastes of hardware and software are identical. On the other hand, standardization increases the degree of product differentiation and the consequent market power that the two firms enjoy. Regarding profits, subtracting (5.4.3)-(5.4.4) from (5.3.7)-(5.3.8), respectively, we have that

$$\begin{aligned}\triangle\pi_1 &= \pi_{1s} - \pi_{1ns}^{in} = \frac{1}{16\overline{Q}}(2\overline{Q}+t)^2 - \frac{1}{16Q}(2Q+t-q)^2 \\ &= \frac{1}{16}[(\frac{1}{\overline{Q}} - \frac{1}{Q})t^2 + \frac{2q}{Q}t + 8q - \frac{q^2}{Q}],\end{aligned}$$

and

$$\begin{aligned}\triangle\pi_2 &= \pi_{2s} - \pi_{2ns}^{in} = \frac{1}{32\overline{Q}}(6\overline{Q}-t)^2 - \frac{1}{32Q}(6Q+q-t)^2 \\ &= \frac{1}{32}[(\frac{1}{\overline{Q}} - \frac{1}{Q})t^2 + \frac{2q}{Q}t + 24q - \frac{q^2}{Q}].\end{aligned}$$

Some computation shows that there exist tariffs $t_1 = \overline{Q} + \sqrt{\overline{Q}^2 + \overline{Q}(8Q-q)}$ and $t_2 = \overline{Q} + \sqrt{\overline{Q}^2 + \overline{Q}(24Q-q)}$ such that the profit difference is positive for firm 1 if $t < t_1$ and positive for firm 2 if $t < t_2$. Since $t_1 < t_2$, standardization benefits both producers if $t < t_1$, and - if less costly adoptable through agreement between the two firms - is a unique subgame perfect equilibrium. Otherwise, non-standardization is the unique subgame perfect equilibrium under our assumption of explicit agreement on standardization.

To decide on the standardization choices of firms for a given government tariff level, we should take into consideration the restriction of $-2Q+5q < t < 6Q-3q$ which is imposed under the non-standardization and independent taste parameters case. Simple algebra shows that $t_1 > 6Q-3q$ when Q is sufficiently close to q and the reversal holds otherwise. Moreover, we have that $t_2 > 6Q-3q$. Therefore, under the restriction on tariffs that $t < 6Q-3q$, firm 2 always prefers standardization. Under the same restriction, firm 1 prefers also standardization if $t_1 > 6Q-3q$ or if Q is sufficiently close to q. Otherwise, firm 1 prefers standardization if $t < t_1$ and non-standardization if $t_1 \leq t < 6Q-3q$. In summary, we conclude that under the restriction of tariffs that $t < 6Q-3q$, the two firms are always in favour of standardization if Q is sufficiently close to q. Otherwise, the two firms choose standardization if $t < t_1$, and non-standardization if $t_1 \leq t < 6Q-3q$. If we call the policy in which the tariff level goes down below the benchmark t_1 *trade liberalization*, and *trade protectionism*, otherwise, we have then the following proposition.

Proposition 5.5.1 *If the quality differential between hardware and software is sufficiently large, then trade liberalization leads to standardization while protectionism leads to non-standardization; otherwise, standardization is a strategic choice of the two firms.*

□

This proposition suggests that the standardization choices of firms are heavily effected by the government's trade policy through tariffs. This observation is consistent to the finding derived from Katz and Shapiro (1994). Given our restriction of tariffs that $-2Q + 5q < t < 6Q - 3q$, the two firms decide on standardization depending on the overall advantages they may enjoy. For firm 2, the advantage enjoyed by acting as a quality leader is balanced by the cost disadvantage created by government's tariff and by acting as an entrant. Firm 2 then prefers standardization. The reversal is true for firm 1. The advantage enjoyed by firm 2 is the disadvantage of firm 1, and vice versa. Furthermore, the advantage and disadvantages of firm 1 will be balanced if the tariff imposed by the government is sufficiently low, and standardization is therefore also preferred. Otherwise, firm 1 will enjoy overall advantages over firm 2 because of the heavily government-imposed tariff on firm 2 or the strong government's protection from foreign competition. Firm 1 then prefers non-standardization. Because standardization can not survive unless both firms agree on it, non-standardization is then the choice of the two firms if the government-imposed tariff is sufficiently high or if $t_1 \leq t < 6Q - 3q$.

An immediate implication of the proposition is that if standardization was imposed by the government, removing or increasing trade barriers would induce the domestic and the foreign firms to lobby for the same political platform (in favour of or against standardization).

5.6 Optimal trade policy

In the previous section we have seen that the government's trade policy effects the standardization choices of firms. Standardization depends on the government's decision about the tariff level. In this section, we consider the reversed situation. The government's trade policy is also effected by the standardization choices of the firms. For this consideration, we may distinguish between two cases. In the first case, the government may commit itself to a tariff level before the standardization choices of firms. In the alternative case, it is assumed that standardization decision is more irreversible than trade policies, which is particularly true if the cooperative choice of standardization implies sunk investments, and trade policies are discretionary. In this case, it seems natural to assume that firms make their standardization decisions before the government's trade policy decisions.

5.6.1 The government being a leader

In the first case let us consider the government acting as a leader to both firms. This situation can be treated as if the government enters the original game in stage 0, where the government specifies the tariff levels taking into account the standardization choices of firms as described previously. Because the standardization choices of firms effect the national surplus through both the consumer surplus and the domestic firm's profit, the government has to take into account the change of regime caused by the tariff level.

By definition, the domestic surplus W is given by the domestic consumer surplus plus the domestic firm's profit plus the tariff revenue. Let $W_s(t), W_{ns}^{id}(t), W_{ns}^{in}(t)$ represent W in cases of standardization, non-standardization with identical and with independent taste parameters, respectively. Then, taking into account the fact that $J = L = K$ we have for any given tariff level t that

$$\begin{aligned} W_s(t) = W_{ns}^{id}(t) &= \int_0^K \tfrac{1}{2}(Y + V_0 - \overline{P}_{1s})dk + \int_K^2 \tfrac{1}{2}(Y + V_0 + \overline{Q}k - \overline{P}_{2s})dk + \tfrac{K}{2}\overline{P}_{1s} \\ &+t(1 - \tfrac{K}{2}) = Y + V_0 - \tfrac{1}{32\overline{Q}}(6\overline{Q} - t)^2 + \tfrac{1}{64\overline{Q}}(60\overline{Q}^2 - 4\overline{Q}t - t^2), \end{aligned}$$

and

$$\begin{aligned} W_{ns}^{in}(t) &= \int_{2q}^S g(k)(Y + V_0 - \overline{P}_{1ns}^{in})dk + \int_S^{2Q} g(k)(Y + V_0 + k - \overline{P}_{2ns}^{in})dk \\ &+G(S)\overline{P}_{1ns}^{in} + t(1 - G(S)) \\ &= \tfrac{Q-q}{Q}(Y + V_0) + \tfrac{q}{2Q}(Q - \tfrac{q}{2} + \tfrac{t}{2}) - \tfrac{1}{4Q}(\tfrac{3}{2}Q - \tfrac{3}{4}q - \tfrac{1}{4}t)(\tfrac{1}{2}Q - \tfrac{1}{4}q + \tfrac{5}{4}t) \\ &+\tfrac{1}{8Q}t(6Q + q - t). \end{aligned}$$

Taking into account the government's tariff restrictions under non-standardization we define t_s, t_{ns}^{id}, and t_{ns}^{in} as $t_s = min\{argmax_{t\geq 0}W_s(t), 6Q - 3q\}$, $t_{ns}^{id} = min\{argmax_{t\geq 0}W_{ns}^{id}(t), 6\overline{Q}\}$, and $t_{ns}^{in} = min\{argmax_{t\geq 0}W_{ns}^{in}(t), 6Q - 3q\}$. Then, t_s, t_{ns}^{id}, and t_{ns}^{in} are the tariff levels which maximize domestic surplus in the standardization regime, in the non-standardization regimes with identical taste parameters and with independent taste parameters, respectively. Optimization of the domestic surplus shows that

$$t_s = min\{\tfrac{10}{3}\overline{Q}, 6Q - 3q\} = \begin{cases} \tfrac{10}{3}\overline{Q}, & \text{if } Q >> q, \\ 6Q - 3q, & \text{otherwise,} \end{cases}$$

$$t_{ns}^{id} = \tfrac{10}{3}\overline{Q},$$

and

$$t_{ns}^{in} = min\{\tfrac{10}{3}\overline{Q} + 3q, 6Q - 3q\} = \begin{cases} \tfrac{10}{3}\overline{Q} + 3q, & \text{if } Q >> q, \\ 6Q - 3q, & \text{otherwise,} \end{cases}$$

at which

$W_s(t_s) = W_{ns}(t_{ns}^{id}) = Y + V_0 + \frac{7}{9}\overline{Q}$, if $Q >> q$,
and

$$W_{ns}(t_{ns}^{in}) = \begin{cases} \frac{Q-q}{Q}(Y+V_0) + \frac{4}{3}\frac{q}{\overline{Q}Q} - \frac{1}{12Q}(4Q^2 + 16Qq + 3q^2), \text{ if } Q >> q, \\ \frac{Q-q}{Q}(Y+V_0) + \frac{5}{2}\frac{q(2Q-q)}{Q}, \text{ otherwise.} \end{cases}$$

For ease of exposition, let us denote $t^* = 6Q - 3q$. To discuss optimal trade policy or the optimal tariff level, let us first notice that the two firms are indifferent between standardization and non-standardization choices when the consumer's tastes of hardware and software are identical. The government will then choose the tariff level at t_s to optimize the domestic surplus. The analysis thus leads to the following proposition.

Proposition 5.6.1 *When the consumer's tastes of hardware and software are identical, the government chooses the tariff level at t_s while the two firms choose randomly standardization or non-standardization.*

□

The more interesting case comes when the consumer's tastes of hardware and software are independent of each other. In this case, we may distinguish further between the case that the hardware quality Q is sufficiently larger than the software quality q (or that $\frac{q}{Q}$ goes to 0) and the case that the hardware quality Q is sufficiently close to the software quality q (or that $\frac{q}{Q}$ goes to 1).

The quality difference between hardware and software is sufficiently large. In this case, the following results can be directly derived.

Lemma 5.6.1 *If Q is sufficiently larger than q, such that $\frac{q}{Q} < 0.172$, then both $t_s < t_1$ and $t_{ns}^{in} < t_1$ hold.*

Proof. First of all, given that Q is sufficiently larger than q we have that $t_s = \frac{10}{3}\overline{Q}$. Suppose that $t_s \geq t_1$. Then, we have that $\frac{10}{3}\overline{Q} \geq \overline{Q} + \sqrt{\overline{Q}^2 + \overline{Q}(8Q-q)}$, or that $\frac{q}{Q} \geq \frac{32}{49}$. Contradiction to the condition that $\frac{q}{Q} < 0.172$.

Similarly, given that $\frac{q}{Q} < 0.172$ we have that $t_{ns}^{in} = \frac{10}{3}\overline{Q} + 3q$. Suppose that $t_{ns}^{in} \geq t_1$. Then, we have that $\frac{10}{3}\overline{Q} + 3q \geq \overline{Q} + \sqrt{\overline{Q}^2 + \overline{Q}(8Q-q)}$, or that $143\frac{q}{Q} + 256(\frac{q}{Q})^2 \geq 32$. Given the condition that Q is sufficiently larger than q, or that $\frac{q}{Q} < 0.172$, this inequality does not hold. Contradiction.

□

Our former analysis shows that $t_1 < t^*$, and the intervals $(0, t_1)$ and (t_1, t^*) are standardization and non-standardization regimes, respectively, provided that $\frac{q}{Q} < 0.172$ holds. Therefore, Lemma 5.6.1 shows that t_s falls into the right standardization regime while t_{ns}^{in} does not fall into the right non-standardization regime. Hence, to ensure that the two firms choose non-standardization, the government will choose tariff t_1. This is because that the surplus function is downwards-sloping to the right of t_{ns}^{in}. Consequently, to decide on the optimal tariff level, it is sufficient to compare $W_s(t_s)$ with $W_{ns}(t_1)$. The comparison leads directly to the following proposition.

Proposition 5.6.2 *Suppose that consumers' tastes of hardware and software are independent and that Q is sufficiently larger than q. Then, the government chooses the tariff level at t_s and standardization follows.*

Proof. Direct comparison shows that $W_s(t_s) > W_{ns}(t_{ns}^{in})$ if Q is sufficiently larger than q. Moreover, it is obvious that $W_{ns}(t_{ns}^{in}) \geq W_{ns}(t_1)$ by definition. Therefore, we have that $W_s(t_s) > W_{ns}(t_1)$ holds. Because $W_s(t_s)$ and $W_{ns}(t_1)$ are the maximum surplus that the government can expect under standardization and non-standardization choices of firms, respectively, the government will then choose the tariff level of t_s and standardization follows.

□

The quality difference between hardware and software is sufficiently small. In this case, the following results can be directly derived.

Lemma 5.6.2 *If Q is sufficiently close to q, such that $\frac{q}{Q} > 0.372$, then $t_s = t_{ns}^{in} = t^* < t_1$.*

Proof. Given that Q is sufficiently close to q, our former analysis shows that $t_s = t_{ns}^{in} = 6Q - 3q = t^*$. Suppose that $t^* \geq t_1$. We have that $6Q - 3q \geq \overline{Q} + \sqrt{\overline{Q}^2 + \overline{Q}(8Q - q)}$ or $16 \geq 49\frac{q}{Q} - 16(\frac{q}{Q})^2$. Contradiction to the condition that $\frac{q}{Q} > 0.372$.

□

This lemma shows that non-standardization could never be the firms' choice. In fact, the maximum tariff level which the government can choose such that non-standardization is the feasible choice is t^*. When $\frac{q}{Q}$ goes to 1, however, t^* is less than t_1, which leads the two firms to prefer standardization. Given the fact that standardization is the feasible choice of firms, the government prefers a tariff level of t_s, which does fall into the standardization regime $(0, t_1)$. Standardization then follows.

Proposition 5.6.3 summarizes the result.

Proposition 5.6.3 *Suppose that consumers' tastes of hardware and software are independent and that $\frac{q}{Q} > 0.372$. Then, the government chooses the tariff level at $t_s (= t^*)$ and implements standardization.*

□

Thus far, we have seen that when the government could commit to a tariff level before the standardization choices of firms, standardization is always implemented independent of the quality difference between hardware and software. The optimal trade policy or tariff level may, however, change depending on the quality difference between hardware and software. When the difference is sufficiently large, a tariff level at t_s is chosen. Otherwise, the tariff level at t^* is preferred.

5.6.2 The government being a follower

In the alternative case, the government and the firms change their positions in the sequential game they played. The firms decide first on standardization, and then the government sets up the tariff level. Finally, price competition takes place between these two firms. More precisely, the timing of the game is as follows.

Stage 0: Firms decide on standardization simultaneously.

Stage 1: The government chooses a tariff level.

Stage 2: Firms compete in prices by playing a Stackelberg game with firm 1 being the leader.

This game is solved again by backwards induction. We have already the solution of stage 2. Then, let us consider the government's decisions given the firms' choices of standardization. The government implements its optimal tariff policies under the standardization or non-standardization regime chosen by the two firms. When the consumers' tastes are identical, the two firms are indifferent between standardization and non-standardization. Therefore, the standardization choices of firms and the government's decision on tariff level are independent of each other. The government then chooses t_s to optimize domestic surplus, and the two firms may choose standardization or non-standardization randomly. The following proposition states the result.

Proposition 5.6.4 *When consumers' tastes of hardware and software are identical, the government chooses the tariff level at t_s while the two firms choose standardization or non-standardization randomly.*

$\square$

The more interesting case comes when the consumers' tastes of hardware and software are independent. To specify the government's decision on tariff levels, we need to distinguish between the cases that the quality difference of hardware and software are sufficiently large and small.

The quality difference between hardware and software is sufficiently large, i.e. satisfies the condition $\frac{q}{Q} < 0.172$. In this case, the government will implement its optimal tariff level of t_s under standardization choices of firms and of t_{ns}^{in} otherwise. Now, in stage 0 the two firms have to decide on standardization by anticipating the government's reaction to a given tariff level. Lemma 5.6.1 shows, however, that both t_s and t_{ns}^{in} fall into the standardization tariff regime $(0, t_1)$ while the non-standardization regime is (t_1, t^*). Therefore, the two firms will agree on standardization, and the tariff level of t_s is consequently implemented by the government. This can be stated in the following proposition.

Proposition 5.6.5 *When the quality difference between hardware and software is sufficiently large, i.e. satisfies the condition $\frac{q}{Q} < 0.172$, the two firms agree on standardization, and the government chooses the tariff level of t_s.*

$\square$

The quality difference between hardware and software is sufficiently small or $\frac{q}{Q} > 0.372$. In this case, the government still chooses the tariff level of t_s under standardization and t_{ns}^{in} under non-standardization. Anticipating the choices of tariff levels by the government, the two firms decide then on standardization in the first stage. Lemma 5.6.2 shows that $t_{ns}^{in} = t_s = t^* < t_1$. This means that non-standardization is an infeasible choice of the two firms. Standardization, however, increases both firms' profits and will be chosen. Summarizing, we have the following proposition.

Proposition 5.6.6 *If the quality difference between hardware and software is sufficiently small, i.e. satisfies the condition* $\frac{q}{Q} > 0.372$*, the two firms agree on standardization and the government chooses the tariff level of* $t_s (= t^*)$*.*

□

5.6.3 Comparison between government as a leader and a follower

We may now compare the case that the government commits itself to a tariff level before the standardization choices of firms with the case that it cannot. Our former analysis shows that when the consumers' tastes of hardware and software are identical, the standardization choices of firms are independent of the government's trade policies, and thus independent of the timing of the game in which the government's tariff is chosen.

When the consumers' tastes are independent, two cases must be distinguished, the quality difference between hardware and software is sufficiently high or small. The government chooses the tariff level of t_s in the former case and t^* in the latter case. The two firms agree on standardization in either case. Moreover, these choices are not effected by the government precommitment to a tariff level. Thus, in summary we have the following.

Proposition 5.6.7 *The government's precommitment to a tariff policy does not change either surplus or tariff level; the standardization choices of firms are independent of the government's trade policies when the consumers' taste parameters are identical.*

□

5.7 Conclusion

In this chapter we have studied the effects of government's trade policies on incentives of firms to standardize their products. We have characterized the nature of standardization regimes that will occur according to the level of domestic protection. The optimal trade policies are then discussed by distinguishing between government as a leader and a follower.

The firms are assumed in our study to produce system goods, which consists of one unit of hardware and one unit of software. The foreign firm is "superior" in producing both hardware and software, but a follower in pricing as an entrant, and taxed by government's tariffs. One interesting fact discovered in our study is that government's tariffs or trade policies effect - and are effected by - the standardization choices of firms. The former decides on the firms' standardization choices while the latter decides on the optimal government's trade policies. These effects can be decided on for given consumers' taste parameters of hardware and software and given the quality difference between hardware and software.

One aspect of our study is on the effect of government's tariffs on standardization choices of firms. When consumers' taste parameters are identical, the standardization choices of firms are independent of government's tariffs. When consumers' tastes of hardware and software are independent, however, government's tariffs effect the standardization choices of firms. On the one hand, government's tariffs may always lead the two firms to agree on standardization if the quality difference between hardware and software is sufficiently small. On the other hand, when the quality difference between hardware and software is sufficiently large, i.e. satisfies the condition $\frac{q}{Q} < 0.172$, protectionism or increasing government's tariffs erodes the foreign firm's technology advantages in both hardware and software, and leads the foreign firm to agree on standardization. The domestic firm, however, may either agree or does not agree on standardization depending on the government's tariff level. Strong protectionism may provide the domestic firm an overall advantage to reject standardization while trade liberalization may balance his advantage and disadvantage such that he agrees on standardization. Since under our assumptions standardization can not be achieved unless both firms agree on it, an interesting political implication follows immediately. When the domestic government has the possibility to impose, in advance, the standardization regime, then the government can lead the two firms to lobby in the same direction (oppose or support the given regime).

Another aspect of our study is the policy implications of the endogenous standardization regimes to the nature of optimal tariffs. In particular, we have shown that the unanimous agreement of the two firms on standardization induces a trade-off between rent shifting and standardization motives in the determination of optimal tariff levels. In that context, we have discussed that there is no advantage for the domestic government to precommit to a tariff level. In particular, we have shown that neither surplus nor the optimal tariff level is changed by the government acting as a leader.

References

EINHORN, M.A., 1992, "Mix and match standardization with vertical product dimensions," *Rand Journal of Economics 23*, 535-546.

GABSZEWICZ, J.J. AND J.F., THISSE, 1979, "Price competition, quality, and income disparities," *Journal of Economic Theory*, 20, 340-359.

JEANNERET, M.-H. AND T. VERDIER, 1996, "Standardization and protection in a vertical differentiation model," *European Journal of Political Economy*, 12, 253-271.

KATZ, M. AND C., SHAPIRO, 1994, "System competition and network effects," *Journal of Economic Perspectives*, 8, 93-115.

MATUTES, C. AND P. REGIBEAU, 1996, "A selective review of the economics of standardization: Entry deterrence, technological progress and international competition," *European Journal of Political Economy*, 12, 183-209.

NICOLAS, F., 1988, "Des normes communes pour les entreprises," Document de la commission des Communautés européennes (Office des publications officielles des Communautés européennes, Luxembourg).

TIROLE, J., 1988, *The theory of industrial organization*, The MIT Press, Cambridge, MA.

Chapter 6

Desirability of tying by durable-goods producers

6.1 Introduction

In this chapter, we consider durable-goods industries where firms not only produce durable-goods but also supply maintenance and repair services to their customers. Information about complex, long-lived durable-goods may be costly and necessarily imperfect. This tends to make perfect, complete contracting infeasible and a contract law less useful in the maintenance and repair services case. Suppose that contracts specifying future repair prices cannot be written down. Then, an *aftermarket*[1] situation arises, where *opportunism* (Williamson (1985)) may lead the producers to manipulate pricing to harvest supranormal profits. We call the primary product market where durable-goods are sold the *equipment market.* The durable-goods and their maintenance and repair services are called *equipment* and *aftermarket-goods*, respectively.

In several recent antitrust suits, the manufacturers of complex durable goods, such as those of Kodak, Prime Computer, Data General, Northen Telecom, Picker, Unisys, Xerox, and Siemens, have been accused of restraining trade by *tying* the aftermarket sales of maintenance and repair services to the purchase of the durable-goods. For example, in the *Kodak* case, the Independent Service Organizations (ISOs) brought an antitrust action against Kodak to recover for policies Kodak introduced that limited the availability to ISOs of replacement parts for copying and micrographic equipment manufactured and

[1]Following Shapiro and Teece (1994) we define an "aftermarket" as a place where "aftermarket transaction" takes place. This aftermarket transaction has two characteristics: (1) the aftermarket product or services is *used together with a primary product*, and (2) the aftermarket product or services is *purchased after the primary product.*

sold by Kodak. The ISOs alleged that Kodak had unlawfully tied the sale of services for its machines to the sale of parts, in violation of Section 1 of the Sherman Act, and had unlawfully monopolized and attempted to monopolize the sale of services and parts in violation of Section 2 of the Sherman Act.[2]

This vertical restraint of tying, imposed by manufacturers of complex equipment to refrain their customers from selling or installing repair parts produced by competing firms, which in effect means that consumers must purchase their full requirements from the original equipment makers, has, however, caused some confusion in the courts. In an earlier example of 1936, the United States Supreme Court affirmed a decision of a lower court approving General Motors' requirement that GM customers install only GM replacement parts. But following the tightening of the Clayton Act Section 3 criteria in the *Standard Stations* decision, the early General Motors' decisions were criticized by some courts. In 1959, an appellate court ruled that attempts by the Ford Motor Company to force its customers to sell or install Ford-made or approved parts only might be found illegal if they substantially lessened competition. For more details, we refer to Scherer and Ross (1990). In a recent example from the United States also, the *Prime* vs *Kodak* case, an independent service company alleged that Prime (now Computervision) had tied the sale of software support and upgrades to the purchase of hardware maintenance from Prime. Prior to the Supreme Court decision in the Kodak case, the Sixth Circuit had accepted Prime's argument that competition in the equipment market would necessarily discipline aftermarket prices. The Supreme Court overturned this decision shortly after deciding in the Kodak case. The Sixth Circuit then decided that sufficient evidence had been presented to support a finding that it was profitable for Prime to monopolize the aftermarket services [3].

The common feature in these cases is that the defendants manufacture complex durable equipment for which customers demand services, support, parts, or upgrades over many years after the initial sale. The parts and services are complements to equipment: Lowering the price of equipment raises the demand for parts and services, and vice versa. In these cases, the economic interaction between the original equipment market and the aftermarket is central to the analysis.

The manufacturer's two competing incentives, namely on the one hand extracting profits from customers who are locked-in into a brand of equipment by raising prices on the associate aftermarket products, and on the other hand increasing profits from new equipment sales by establishing a reputation for selling equipment with low maintenance

[2] See Shapiro and Teece (1994), for more details.

[3] See Borenstein, MacKie-Mason and Netz (1995), for more details.

costs, have been discussed in detail in Voortman (1993) and Shapiro and Teece (1994), and formulated and analysed theoretically in Borenstein, MacKie-Mason and Netz (1996) and Blair and Herndon (1996). Economic theory, however, does not support the common argument by equipment manufacturers that strong primary market competition will discipline aftermarket behaviour. As found by Borenstein et al. (1996), despite losing profits in equipment sales from a reputation for exploiting locked-in customers, equipment manufacturers have indeed incentives to exercise market power in their proprietary aftermarkets. The same result is found in de Bijl (1995) for the monopoly case.

This chapter gains additional insights into above issues by modelling durable-goods markets explicitly. A durable-goods market consists of an equipment market and an aftermarket, both horizontally differentiated. The question we ask is: Although firms have incentives to exercise monopoly power once their aftermarkets are tied to their equipment markets, do firms have really incentives to tie their aftermarkets to their equipment markets ? We study a duopoly to consider the incentives of durable-goods producers to tie their aftermarkets to their primary markets. The strategies adopted by the producers and welfare implications of these strategies are analysed explicitly. We show that durable-goods producers will prefer to compete on their aftermarkets rather than protect their proprietary aftermarkets through tying if the consumer's reservation price is sufficiently low. If the consumer's reservation price is sufficiently high, however, these two producers may prefer either to tie or to compete on their aftermarkets provided that the aftermarkets are sufficiently less valuable; and tying is particularly preferred in this case if these two firms could coordinate on it. If the aftermarkets are sufficiently valuable, however, no agreement can be reached between these two firms. We also show that social preference may be consistent with the firms' choices of tying. The analysis then confirms the finding of Blair and Herndon (1996) that as far as the competitive and monopoly equipment markets are considered, the vertical restraint of tying has little to do with antitrust concerns.

To our analysis in this chapter, the *life-cycle cost* concept introduced in Blair and Herndon (1996), and Shapiro and Teece (1994) also, is worth of mentioning. Life-cycle cost is the cost concerned by the buyers of durable-goods in their decision making process, in which they take into account not only the original purchase price of the equipment, but also expected maintenance costs, including that of supplies, parts, and services. It is assumed that buyers can perform effectively life-cycle cost calculations and compare products before making a purchase. Presumably, this means that under the vertical restraint of tying, a buyer will select among alternatives while recognizing that buying a durable-goods from a producer involves a commitment to paying for future maintenance and repair services in addition to the immediate price of that durable-good. Without the vertical restraint of tying, however, a buyer makes her choice based on what she perceives to be the best combination of the equipment and its maintenance and repair services. This means that the buyer makes her choice on the basis of what she perceives to be the best deal to her. Thus, competition takes place whenever the initial purchase commitment is made in the durable-goods markets.

The life-cycle cost concept leads us to a world where a customer perceives a durable-goods, including the equipment and its maintenance and repair services, as a "pseudo-system goods", and purchases from one or two firms by maximizing her total discounted utility. Thus, it seems that firms spread over an imperfectly competitive market, being horizontally differentiated in two dimensions, one for the equipment market and the other for the aftermarket. Firms choose between protecting and opening their proprietary aftermarkets, either through the vertical restraint of tying or opening their proprietary aftermarkets to competition in order to maximize the present values of their total discounted profits. This formulation is quite realistic because although actual equipment markets are typically reasonably competitive, as discussed in Blair and Herndon (1996), the *brands* of both the equipment and the maintenance and repair services are differentiated.

This chapter is closely related to the literature on compatibility decisions of firms producing system goods in the absence of network externalities. See, for example, Economides (1989) and Boom (1995). A system goods consists of a set of components. Any incomplete set of components of a system goods is useless to the customers. In particular, this chapter can be seen as an extension of the models of Matutes and Regibeau (1988, 1992).

Also related is the literature on customers locked-in and switching cost, considering markets in which buyers make relationship-specific investments when complete contracts cannot be written. Firms, who cannot distinguish between old and new customers, compete to attract customers whom they can exploit later, that is, a firm sells a single goods at a single price (see Klemperer (1987b, 1995), for surveys). The main difference with the literature on consumer switching costs and compatibility decisions of firms producing system goods is that in an aftermarket situation, a firm sells *separate* goods (equipment and aftermarket-goods), each at a different price.

In our consideration of the duopoly case two questions will be focused on. First, which choices will the duopolists make: Imposing the vertical restraint of tying to protect their proprietary aftermarkets from competition, or opening their aftermarkets to competition? Second, what are the welfare implications of these choices?

We solve a two-stage game for its symmetric subgame perfect equilibria. In the first stage of the game, two firms decide simultaneously on whether to use the vertical restraint of tying to protect their aftermarkets. In the second stage, the two firms compete in price while taking the other firm's price as given. We present the model in Section 6.2. Then, three cases of tying, tying by both firms, no firm choosing tying, and unilateral tying, are discussed in Sections 6.3, 6.4 and 6.5, separately. Equilibria are then analysed in Section 6.6. In Section 6.7, we provide an analysis of welfare implications of the durable-goods producers' choices of tying, and Section 6.8 concludes.

6.2 The model

We consider a two-period model. Two firms, called A and B, offer horizontally differentiated durable-goods in the first period and differentiated aftermarket-goods in the second period. Both durable-goods and aftermarket-goods are substitutes. The unit cost of producing a durable-goods for both firms is c_0, whereas repairing the durable-goods costs both firms $c \geq 0$. The parameters satisfy that $c < c_0$, that is, repairing is less costly than producing a new product, or producing a spare part is less costly than producing a complete product. There are no economies of scope and also no network externalities. Throughout the chapter, c_0 and c are assumed to be sufficiently small in order to guarantee that there exist prices such that the duopolists are willing to produce. If the firms choose to monopolize their aftermarkets through tying, then only two options are available for customers who are in need of aftermarket-goods: X_{AA}, firm A's durable-goods and aftermarket-goods, or X_{BB}, firm B's durable-goods and aftermarket-goods. If the aftermarkets are exposed to competition, however, customers have two additional options: X_{AB}, firm A's durable-goods and firm B's aftermarket-goods, or X_{BA}, firm B's durable-goods and firm A's aftermarket-goods.

In period $t \in \{1,2\}$, the duopolist i with $i \in \{A,B\}$ charges a price $p_{ti} \geq 0$ for his products. He discounts his future profit with a factor $\delta \in [0,1)$, which means that aftermarkets are always valuable and may be even as valuable as primary markets. The duopolists maximize the present values of their total discounted profits.

In the first period, customers buy their equipment from one of the two firms in the equipment market. In the second period, customers either use the goods they bought in the first period again by buying aftermarket-goods from one of the firms to have their original equipment repaired, or repurchase new equipment. From a customer's point of view, the repaired goods have depreciated values with a depreciation factor equal to the firms' discount factor.

If the two firms try to monopolize their aftermarkets, then customers are locked-in fully into the aftermarkets, to the extent that customers who purchase the aftermarket-goods can only purchase from the firm from which they bought in the first period. If the aftermarkets are exposed to competition, however, customers may purchase aftermarket-goods from either firm.

Customers are assumed to distribute uniformly over a unit square with density 1 (see **Figure** 6.1). Firm A is located at the origin $(0, 0)$, and firm B is located at (1,1). A customer located at (x_1^0, y_1^0) has a preferred equipment that is x_1^0 away from firm A's equipment and a preferred aftermarket-goods that is y_1^0 away from firm A's aftermarket-goods. Similarly, the distances between the customer's preferred point and firm B's equipment and aftermarket-goods are $1 - x_1^0$ and $1 - y_1^0$, respectively.

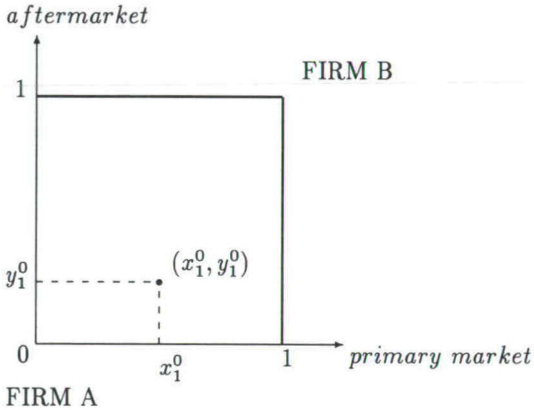


Figure 6.1 Consumers distribute uniformly over a unit square.

Therefore, a customer has a surplus of

$$U(p_{1i}, d_{1i}) = r - p_{1i} - \alpha d_{1i}$$

from buying one unit of the equipment of firm $i, i \in \{A, B\}$, and a surplus of[4]

$$U(p_{2i}, d_{2i}) = \beta(r - p_{2i} - \alpha d_{2i})$$

from buying one unit of the aftermarket-goods $i, i \in \{A, B\}$, where $\beta = 1 - \delta$, with $\beta \in [1, 0)$, represents the ratio of the value after depreciation, $r > 0$ is the customer's reservation price which is identical for all consumers, d_{ti} with $t \in \{1, 2\}$ is the distance between the customer's preferred specification of the equipment (aftermarket-goods) and

[4]When a customer buys one unit of the aftermarket-goods and has her equipment bought in the first period repaired, she gains a repaired good with a depreciated value in the second period.

the specification of the equipment (aftermarket-goods) sold by firm i, $i \in \{A, B\}$ (in **Figure** 6.1, $d_{1A} = x_1^0$, $d_{1B} = 1 - x_1^0$, $d_{2A} = y_1^0$, $d_{2B} = 1 - y_1^0$), and $\alpha > 0$ represents the degree of product differentiation. The parameters α, c_0, c are constant while r, β, and δ are variables known by firms. We assume that $r > c_0 > c$, that is, that customers' reservation price is larger than the firms' marginal costs of producing not only aftermarket-goods but also equipment, so that firms are able to produce profitably. The present value of the total surplus of a customer is

$$U(p_{1i}, p_{2j}, d_{1i}, d_{2j}) = (1+\beta)r - p_{1i} - \beta p_{2j} - \alpha(d_{1i} + \beta d_{2j}),$$

if he purchases equipment from firm i and aftermarket- goods from firm j, $i, j \in \{A, B\}$. Customers decide on their purchases in the first period.

We assume that a customer expects a future repair price equal to the repair price she observes when she enters the market in the first time to buy the equipment.[5] This allows the firm to establish instantly a reputation for not imposing the vertical restraint of tying on customers in need of a repair.

6.3 Tying aftermarkets by both firms

Given that both firms choose to tie their respective aftermarkets, an equipment customer of one durable-goods producer is excluded from the purchase of the other durable-goods producer's aftermarket-goods. So, durable-goods customers can only go to their former firm's aftermarkets for the maintenance and repair services. We may distinguish the local monopolists case from the direct competitors case in order to derive the equilibrium levels of prices and profits[6] (see **Figure** 6.2).

Local monopolists. In this case[7], firm A serves all customers for which $(1+\beta)r - p_{1A} - \beta p_{2A} - \alpha(d_{1A} + \beta d_{2A}) \geq 0$. Therefore, the customers served by firm A are located below the line with equation

$$d_{1A} + \beta d_{2A} = \frac{(1+\beta)r - p_{1A} - \beta p_{2A}}{\alpha}, \tag{6.3.1}$$

so that firm A's total discounted profit is

[5]Expectations are required to be fulfilled in equilibrium as argued in de Bijl (1995).

[6]We do not, however, discuss the intermediate case, where the two firms' markets just touch each other, but consumers on the markets' boundary stay out of the markets.

[7]From now on, the discussion for firm A holds also for firm B. For ease of exposition, we demonstrate the equilibrium configurations only for firm A, and assume that the same holds for firm B.

$$\pi_A = \frac{1}{2\beta\alpha^2}[(p_{1A} - c_0) + \beta(p_{2A} - c)][(1+\beta)r - p_{1A} - \beta p_{2A}]^2.$$

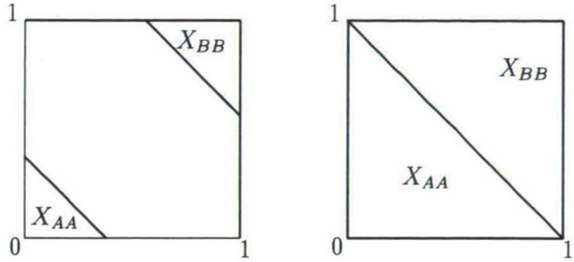


Figure 6.2 Tying aftermarkets by both firms (case $\beta = 1$)

Since customers in need of repair services have the option to repurchase new equipment instead of buying the aftermarket-goods if the price in the aftermarket is too high, a consumer's utility from consuming aftermarket-goods should not be less than that from buying equipment. Therefore, firm A faces the following optimization problem:

$$\begin{aligned} \text{Max} \quad & \pi_A(p_{1A}, p_{2A}) = \frac{1}{2\beta\alpha^2}[(p_{1A} - c_0) + \beta(p_{2A} - c)][(1+\beta)r - p_{1A} - \beta p_{2A}]^2 \\ \text{s.t.} \quad & U(p_{2A}, d_{2A}) \geq U(p_{1A}, d_{1A}), \\ & U(p_{1A}, p_{2A}, d_{1A}, d_{2A}) = U(p_{2A}, d_{2A}) + U(p_{1A}, d_{1A}) \geq 0. \end{aligned}$$

Maximizing firm A's profit with respect to p_{1A} and p_{2A} and imposing symmetry on the first order condition yield the equilibrium levels of firm A's prices and associate profit as follows:

$$p_{1A}^{TT} + \beta p_{2A}^{TT} = \frac{1}{3}[(1+\beta)r + 2(c_0 + \beta c)], \tag{6.3.2}$$

$$p_{1A}^{TT} \geq r, \tag{6.3.3}$$

$$\pi_A^{TT} = \frac{2}{27\beta\alpha^2}[(1+\beta)r - (c_0 + \beta c)]^3, \tag{6.3.4}$$

where TT denotes tying aftermarkets by both firms.

The inequality (6.3.3) stands for the constraints of the optimization problem and can be derived as follows. First of all, in firm A's market area the second of the constraints given in the optimization problem is trivially satisfied. From the first of the constraints, that is, $U(p_{2A}, d_{2A}) \geq U(p_{1A}, d_{1A})$, or $\beta(r - p_{2A} - \alpha d_{2A}) \geq r - p_{1A} - \alpha d_{1A}$, we have that $p_{1A} \geq (1-\beta)r + \beta p_{2A} + \alpha\beta d_{2A} - \alpha d_{1A}$. Let $d_{1A} = 0$ and substituting 0 for d_{1A} in (6.3.1) yield that $p_{1A} \geq (1-\beta)r + \beta p_{2A} + \alpha\beta \frac{(1+\beta)r - p_{1A} - \beta p_{2A}}{\alpha\beta}$, which leads to that $p_{1A} \geq r$.

This solution is valid as long as the two firms' markets do not overlap in the equilibrium, that is, that $(1+\beta)r - p_{1A}^{TT} - \beta p_{2A}^{TT} - \alpha < 0$ holds, or that the reservation price r is sufficiently low, namely, $r < \frac{3\alpha + 2(c_0 + \beta c)}{2(1+\beta)}$. The customer surplus CS^{TT} and the social welfare SS^{TT} in the equilibrium are

$$CS^{TT} = 2\int_0^{\xi} \int_0^{\frac{1}{\beta}(\xi - g_{1A})} [(1+\beta)r - p_{1A}^{TT} - \beta p_{2A}^{TT} - \alpha(g_{1A} + \beta g_{2A})] dg_{2A} dg_{1A}$$

$$= \tfrac{\alpha}{3\beta}\xi^3 = \tfrac{8}{81\alpha^2\beta}[(1+\beta)r - (\beta c + c_0)]^3, \tag{6.3.5}$$

where $\xi = \frac{(1+\beta)r - p_{1A}^{TT} - \beta p_{2A}^{TT}}{\alpha} = \frac{2}{3\alpha}[(1+\beta)r - (\beta c + c_0)]$, and

$$SS^{TT} = 2\pi_A^{TT} + CS^{TT} = \tfrac{20[(1+\beta)r - (c_0 + \beta c)]^3}{81\alpha^2\beta}. \tag{6.3.6}$$

Direct competitors. Under direct competition the whole market is served.[8] Once again, the situation that we shall consider is that a customer who purchases the durable-goods from firm A in the equipment market is fully locked-in, and will also buy her aftermarket-goods from firm A. The same holds for firm B. A customer will buy from firm A if

$$p_{1A} + \beta p_{2A} + \alpha(d_{1A} + \beta d_{2A}) \leq p_{1B} + \beta p_{2B} + \alpha(d_{1B} + \beta d_{2B}),$$

or if she is located below the line defined by the equation

[8]We do not discuss the adjacent market case here, in which firms' markets just touch each other but consumers on the market boundary stay out of the markets. This is the case when the consumer's reservation price is neither too high nor too low. We also refrain our discussion of this case from the subsequent discussions of Sections 6.4 and 6.5.

$$d_{1A} + \beta d_{2A} = \frac{1+\beta}{2} + \frac{p_{1B} - p_{1A} + \beta(p_{2B} - p_{2A})}{2\alpha}.$$

Then, firm A faces the following optimization problem for given prices of p_{1B} and p_{2B}:

$$\begin{aligned} \max \quad & \pi_A(p_{1A}, p_{2A}, p_{1B}, p_{2B}) = \\ & \frac{(p_{1A} - c_0) + \beta(p_{2A} - c)}{8\beta}(1 + \beta + \frac{p_{1B} - p_{1A} + \beta(p_{2B} - p_{2A})}{\alpha})^2 \\ \text{s.t.} \quad & U(p_{1A}, p_{2A}, d_{1A}, d_{2A}) \geq 0 \\ & U(p_{2A}, d_{2A}) \geq U(p_{1A}, d_{1A}). \end{aligned}$$

Solving this optimization problem yields

$$\begin{aligned} p_{1A}^{TT} + \beta p_{2A}^{TT} &= \tfrac{\alpha(1+\beta)+2(c_0+\beta c)}{2}, && (6.3.7) \\ p_{1A}^{TT} &\geq r, && (6.3.8) \\ \pi_A^{TT} &= \tfrac{\alpha(1+\beta)^3}{16\beta}. && (6.3.9) \end{aligned}$$

This solution is valid as long as the whole market is indeed served at the equilibrium levels of prices, that is, $(1+\beta)r - p_{1A}^{TT} - \beta p_{2A}^{TT} - \alpha > 0$, or if the reservation price is sufficiently high, that is, $r > \frac{\alpha(3+\beta)+2(c_0+\beta c)}{2(1+\beta)}$. The customer surplus and the social welfare are

$$CS^{TT} = 2\int_0^1 \int_0^{1-g_{1A}} [(1+\beta)r - p_{1A}^{TT} - \beta p_{2A}^{TT} - \alpha(g_{1A} + \beta g_{2A})] dg_{2A} dg_{1A}$$

$$= (1+\beta)r - \tfrac{5\alpha(1+\beta)}{6} - (\beta c + c_0), \tag{6.3.10}$$

$$SS^{TT} = (1+\beta)r - (c_0 + \beta c) + \frac{\alpha(1+\beta)}{4}\frac{3\beta^2 - 14\beta + 3}{6\beta}. \tag{6.3.11}$$

Proposition 6.3.1 summarizes the results thus far.

Proposition 6.3.1 *Suppose that both equipment manufacturers protect their respective aftermarkets through tying. Then, the firms are (i) local monopolists and the equilibrium configurations are given in (6.3.2) - (6.3.6) if* $r < \frac{3\alpha+2(c_0+\beta c)}{2(1+\beta)}$*; (ii) direct competitors and the equilibrium configurations are given in (6.3.7) - (6.3.11) if* $r > c + \alpha\frac{(3+\beta)+2(c_0+\beta c)}{2(1+\beta)}$.

□

6.4 Competition on the aftermarkets

In the second case, we consider competition on the aftermarkets. This means that equipment manufacturers do not use the vertical restraint of tying but let their aftermarkets be exposed to competition.[9] Then, customers may choose between four combinations of the equipment and the aftermarket-goods: X_{AA}, X_{AB}, X_{BA} and X_{BB}. we may distinguish between three cases (See **Figure** 6.3), but will discuss the first and third cases in our derivation of the equilibrium levels of prices, profits, and the associate customer surplus as well as social welfare at the second stage.

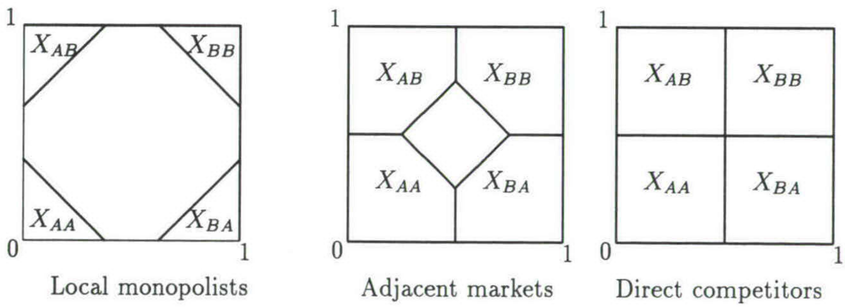


Figure 6.3 Competition on the aftermarkets (case $\beta = 1$)

Local monopolists. Given that the markets formed by different combinations of the equipment and aftermarket-goods are locally monopolized, and that the aftermarkets are exposed to competition, a customer will buy a combination of X_{ij}, $i, j \in \{A, B\}$, if

[9] An alternative situation is that when durable-goods customers have independent preferences across periods, customers' changing tastes may completely nullify the anticompetitiveness of switching costs, and the aftermarkets are quite competitive. This case might arise naturally if the purchasers in different periods are different people, but second-period customers develop switching costs by being exposed to first-period customers' purchases. For example, universities buy computers for students in the first period, and individuals who were students in the first period purchase in the second. Former students have a switching cost of learning the system their university did not purchase, but their underlying experiences, for example, the business application they need, may be uncorrelated with their university ones.

$$U(p_{1i}, p_{2j}, d_{1i}, d_{2j}) = (1+\beta)r - p_{1i} - \beta p_{2j} - \alpha(d_{1i} + \beta d_{2j}) \geq 0. \tag{6.4.1}$$

Therefore, firm A's profit is equal to

$$\pi_A(p_{1A}, p_{2A}, p_{1B}, p_{2B}) = \frac{(p_{1A} - c_0) + \beta(p_{2A} - c)}{2\beta\alpha^2}[(1+\beta)r - p_{1A} - \beta p_{2A}]^2$$
$$+\frac{p_{1A} - c_0}{2\beta\alpha^2}[(1+\beta)r - p_{1A} - \beta p_{2B}]^2 + \frac{\beta(p_{2A} - c)}{2\beta\alpha^2}[(1+\beta)r - p_{1B} - \beta p_{2A}]^2.$$

Then, firm A maximizes $\pi_A(p_{1A}, p_{2A}, p_{1B}, p_{2B})$ under the constraint (6.4.1) and the constraint of

$$U(p_{2A}, d_{2A}) \geq U(p_{1A}, d_{1A}). \tag{6.4.2}$$

From former discussion we know that the above constraints mean that the equilibrium level of firm A's equipment price p_{1A}^{NN} should satisfy that $p_{1A}^{NN} \geq r$, where NN denotes competition on both equipment markets and aftermarkets. Solving this optimization problem and then imposing symmetry on the first order condition by letting that $p_{1A} = p_{1B}$ and $p_{2A} = p_{2B}$ yield the equilibrium outcomes as follows:

$$p_{1A}^{NN} + \beta p_{2A}^{NN} = \tfrac{2r(1+\beta)+3(c_0+\beta c)}{5}, \tag{6.4.3}$$
$$p_{1A}^{NN} \geq r, \tag{6.4.4}$$
$$\pi_A^{NN} = \tfrac{18}{25\beta\alpha^2}[r(1+\beta) - (c_0 + \beta c)]^3. \tag{6.4.5}$$

This local monopolists case is sustained as long as $(1+\beta)r - (p_{1A}^{NN} + \beta p_{2A}^{NN}) - \frac{\alpha}{2} < 0$ holds, or that the reservation price is sufficiently low, $r < \frac{5\alpha+6(c_0+\beta c)}{6(1+\beta)}$. The customer surplus is
$CS^{NN} = 4\int_0^{\xi}\int_0^{\frac{1}{\beta}(\xi - g_{1A})}[(1+\beta)r - p_{1A}^{NN} - \beta p_{2A}^{NN} - \alpha(g_{1A} + \beta g_{2A})]dg_{2A}dg_{1A}$

$$= \frac{2\alpha}{3\beta}\xi^3 = \frac{18}{125\alpha^2\beta}[(1+\beta)r - (c_0 + \beta c)]^3, \tag{6.4.6}$$

where $\xi = \frac{(1+\beta)r - p_{1A}^{NN} - \beta p_{2A}^{NN}}{\alpha} = \frac{3}{5\alpha}[(1+\beta)r - (c_0 + \beta c)]$, and the associate social welfare is

$$SS^{NN} = \frac{126}{125\alpha^2\beta}[(1+\beta)r - (c_0 + \beta c)]^3. \tag{6.4.7}$$

Direct competitors in an entirely served market. In this case, the markets of different combinations of the equipment and the aftermarket-goods just touch each other, and all consumers buy one of these combinations. The market area AA is then bounded by the following lines:

$$d_{1A} = 0,$$
$$d_{2A} = 0,$$

$$(1+\beta)r - p_{1A} - \beta p_{2A} - \alpha(d_{1A} + \beta d_{2A}) = (1+\beta)r - p_{1B} - \beta p_{2A} - \alpha(d_{1B} + \beta d_{2A}),$$
$$(1+\beta)r - p_{1A} - \beta p_{2A} - \alpha(d_{1A} + \beta d_{2A}) = (1+\beta)r - p_{1A} - \beta p_{2B} - \alpha(d_{1A} + \beta d_{2B}).$$

Similarly, we can define the market areas AB and BA. So, firm A's profit function can be written as:

$$\begin{aligned}\pi_A(p_{1A}, p_{2A}, p_{1B}, p_{2B}) = \ & [(p_{1A} - c_0) + \beta(p_{2A} - c)][\tfrac{1}{2} + \tfrac{p_{1B} - p_{1A}}{2\alpha}][\tfrac{1}{2} + \tfrac{p_{2B} - p_{2A}}{2\alpha}] \\ & + (p_{1A} - c_0)[\tfrac{1}{2} + \tfrac{p_{1B} - p_{1A}}{2\alpha}][\tfrac{1}{2} + \tfrac{p_{2A} - p_{2B}}{2\alpha}] \\ & + \beta(p_{2A} - c)[\tfrac{1}{2} + \tfrac{p_{1A} - p_{1B}}{2\alpha}][\tfrac{1}{2} + \tfrac{p_{2B} - p_{2A}}{2\alpha}].\end{aligned}$$

Then, firm A maximizes its profit $\pi_A(p_{1A}, p_{2A}, p_{1B}, p_{2B})$ under the constraint of

$$U(p_{2A}, d_{2A}) \geq U(p_{1A}, d_{1A}).$$

Solving this optimization problem and imposing symmetry on the first order condition yield

$$p_{1A}^{NN} = \alpha + c_0, \tag{6.4.8}$$
$$p_{2A}^{NN} = \alpha + c, \tag{6.4.9}$$
$$\pi_A^{NN} = \frac{\alpha(1+\beta)}{2}. \tag{6.4.10}$$

This equilibrium is sustained as long as $(1+\beta)r - p_{1A}^{NN} - \beta p_{2A}^{NN} - \alpha(\frac{1}{2}+\frac{1}{2}\beta) > 0$ holds, or as long as that the customer's reservation price r is sufficiently high, $r > \frac{3}{2}\alpha + \frac{c_0+\beta c}{1+\beta}$. The customer surplus and the social welfare are given by

$$\begin{aligned} CS^{NN} &= 4\int_0^{\frac{1}{2}}\int_0^{\frac{1}{2}}[(1+\beta)r - p_{1A}^{NN} - \beta p_{2A}^{NN} - \alpha(g_{1A}+\beta g_{2A})]dg_{2A}dg_{1A} \\ &= (1+\beta)r - \frac{5}{4}\alpha(1+\beta) - (c_0+\beta c), \end{aligned} \tag{6.4.11}$$

and

$$SS^{NN} = (1+\beta)r - \frac{1+\beta}{4}\alpha - (c_0+\beta c). \tag{6.4.12}$$

Proposition 6.4.1 states the results derived in this section.

Proposition 6.4.1 *Suppose that both equipment manufacturers leave their respective aftermarkets open to competition. Then, the two firms are (i) local monopolists and the equilibrium configurations are given in (6.4.3)-(6.4.7) if* $r < \frac{5\alpha+6(c_0+\beta c)}{6(1+\beta)}$*; (ii) direct competitors in an entirely covered market and the equilibrium configurations are given in (6.4.8)-(6.4.12) if* $r > \frac{3(1+\beta)\alpha+2(c_0+\beta c)}{2(1+\beta)}$.

□

6.5 Tying aftermarkets unilaterally

In the last case, we consider unilateral tying of the aftermarkets. This means that one equipment manufacturer ties the sale of his aftermarket goods while the other manufacturer does not. Without loss of generality, we assume that firm B uses tying while firm A does not. Then, customers can choose between three combinations of the equipment and the aftermarket-goods: X_{AA}, X_{BA}, and X_{BB}. For the discussion of the equilibrium levels of prices, profits, and the associate customer surplus as well as social welfare, we distinguish, as before, between the local monopoly case and the direct competition case (see **Figure** 6.4).

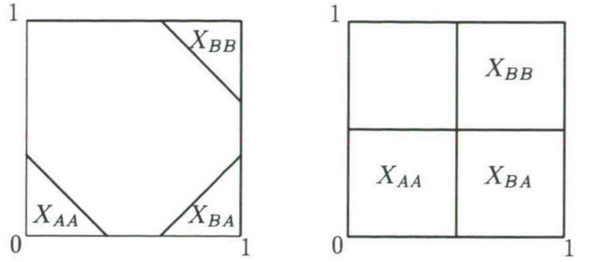


Figure 6.4 Unilateral tying by firm B (case $\beta = 1$)

Local monopolists. In this case, a customer will buy a combination of X_{ij}, $ij \in \{AB, BA, BB\}$, if

$$U(p_{1i}, p_{2j}, d_{1i}, d_{2j}) = (1+\beta)r - p_{1i} - \beta p_{2j} - \alpha(d_{1i} + \beta d_{2j}) \geq 0.$$

Therefore, firm A has the following profit optimization problem to solve:

$$\begin{aligned} \text{Max} \quad & \pi_A(p_{1A}, p_{2A}, p_{1B}) = \frac{(p_{1A} - c_0) + \beta(p_{2A} - c)}{2\beta\alpha^2}[(1+\beta)r - p_{1A} - \beta p_{2A}]^2 \\ & + \frac{\beta(p_{2A} - c)}{2\beta\alpha^2}[(1+\beta)r - p_{1B} - \beta p_{2A}]^2 \\ \text{s.t.} \quad & U(p_{2A}, d_{2A}) \geq U(p_{1A}, d_{1A}), \\ & U(p_{1i}, p_{2A}, d_{1i}, d_{2A}) \geq 0, i \in \{A, B\}, \end{aligned}$$

while for firm B, the profit optimization problem is

$$\begin{aligned} \text{Max} \quad & \pi_B(p_{2A}, p_{1B}, p_{2B}) = \frac{(p_{1B} - c_0) + \beta(p_{2B} - c)}{2\beta\alpha^2}[(1+\beta)r - p_{1B} - \beta p_{2B}]^2 \\ & + \frac{p_{1B} - c_0}{2\beta\alpha^2}[(1+\beta)r - p_{1B} - \beta p_{2A}]^2 \\ \text{s.t.} \quad & U(p_{2B}, d_{2B}) \geq U(p_{1B}, d_{1B}), \\ & U(p_{1B}, p_{2j}, d_{1B}, d_{2j}) \geq 0, j \in \{A, B\}. \end{aligned}$$

It is straightforward to see that for both firms tying aftermarkets unilaterally is strictly dominated by the strategy of competition on the aftermarkets. This is because of the fact that both firms' profits are then lower than the profits they get when competition takes place on their aftermarkets for any given price vector $(p_{1A}, p_{1B}, p_{2A}, p_{2B})$, and the feasible domains are identical. We demonstrate this fact as follows.

Solving these optimization problems yields the equilibrium levels of prices and profits of firm A and firm B as follows:

$$p_{1A}^{NT} = \frac{(1+\beta)r+11c_0-\beta c}{12}, \tag{6.5.1}$$

$$p_{2A}^{NT} = \frac{(1+\beta)r+3\beta c-c_0}{4\beta}, \tag{6.5.2}$$

$$p_{1B}^{TN} = \frac{(1+\beta)r+3c_0-\beta c}{4}, \tag{6.5.3}$$

$$p_{2B}^{TN} = \frac{(1+\beta)r+11\beta c-c_0}{12\beta}, \tag{6.5.4}$$

$$\pi_A^{NT} = \pi_B^{TN} = \frac{91}{864\beta\alpha^2}[(1+\beta)r-(c_0+\beta c)]^3, \tag{6.5.5}$$

where TN and NT denote unilateral tying.

Direct comparison shows that $\pi_A^{NT} = \pi_B^{TN} < \pi_A^{NN}$ holds. The local monopolists case holds as long as $(1+\beta)r - p_{1A}^{NT} - \beta p_{2A}^{NT} - \frac{\alpha}{2} < 0$, $(1+\beta)r - p_{1B}^{TN} - \beta p_{2B}^{TN} - \frac{\alpha}{2} < 0$, and $(1+\beta)r - p_{1B}^{TN} - \beta p_{2A}^{NT} - \frac{\alpha}{2} < 0$. The last inequality subsumes the former two inequalities, and means that the reservation price should be sufficiently low, that is, $r < \frac{(c_0+\beta c)+\alpha}{1+\beta}$.

The associate customer surplus and the social welfare can be calculated as follows:

$$\begin{aligned} CS^{NT} &= \int_0^{\xi}\int_0^{\frac{1}{\beta}(\xi-g_{1A})}[(1+\beta)r - p_{1A}^{NT} - \beta p_{2A}^{NT} - \alpha(g_{1A}+\beta g_{2A})]dg_{2A}dg_{1A} \\ &+ \int_0^{\xi}\int_0^{\frac{1}{\beta}(\xi-g_{1B})}[(1+\beta)r - p_{1B}^{TN} - \beta p_{2A}^{NT} - \alpha(g_{1B}+\beta g_{2A})]dg_{2A}dg_{1B} \\ &+ \int_0^{\xi}\int_0^{\frac{1}{\beta}(\xi-g_{1B})}[(1+\beta)r - p_{1B}^{TN} - \beta p_{2B}^{TN} - \alpha(g_{1B}+\beta g_{2B})]dg_{2B}dg_{1B} \end{aligned}$$

$$= \frac{\alpha}{6\beta}(\xi_{AA}^3 + \xi_{BA}^3 + \xi_{BB}^3) = \frac{155}{1296\alpha^2\beta}[(1+\beta)r-(c_0+\beta c)]^3 \tag{6.5.6}$$

and

$$SS^{NT} = \pi_B^{TN} + \pi_A^{NT} + CS^{NT} = \frac{426}{1296\beta\alpha^2}[(1+\beta)r-(c_0+\beta c)]^3, \tag{6.5.7}$$

where $\xi_{AA} = \frac{(1+\beta)r-(p_{1A}+\beta p_{2A})}{\alpha} = \frac{2[(1+\beta)r-(c_0+\beta c)]}{3\alpha} = \xi_{BB}$, and $\xi_{BA} = \frac{(1+\beta)r-(p_{1B}+\beta p_{2A})}{\alpha} = \frac{(1+\beta)r-(c_0+\beta c)}{2\alpha}$.

Direct competitors. In the direct competitors case, firms A and B compete for solving their respective profit optimization problems. For firm A, this profit optimization problem is

$$\begin{aligned}
\text{Max} \quad & \pi_A(p_{1A}, p_{2A}, p_{1B}, p_{2B}) \\
& = [(p_{1A} - c_0) + \beta(p_{2A} - c)][\frac{1}{2} + \frac{p_{1B} - p_{1A}}{2\alpha}][\frac{1}{2} + \frac{p_{2B} - p_{2A}}{2\alpha}] \\
& +\beta(p_{2A} - c)[\frac{1}{2} + \frac{p_{1A} - p_{1B}}{2\alpha}][\frac{1}{2} + \frac{p_{2B} - p_{2A}}{2\alpha}], \\
\text{s.t.} \quad & U(p_{2A}, d_{2A}) \geq U(p_{1A}, d_{1A}), \\
& U(p_{1i}, p_{2A}, d_{1i}, d_{2A}) \geq 0, i \in \{A, B\},
\end{aligned}$$

while for firm B, it is

$$\begin{aligned}
\text{Max} \quad & \pi_B(p_{1A}, p_{2A}, p_{1B}, p_{2B}) \\
& = [(p_{1B} - c_0) + \beta(p_{2B} - c)][\frac{1}{2} + \frac{p_{1A} - p_{1B}}{2\alpha}][\frac{1}{2} + \frac{p_{2A} - p_{2B}}{2\alpha}] \\
& +(p_{1B} - c_0)[\frac{1}{2} + \frac{p_{1A} - p_{1B}}{2\alpha}][\frac{1}{2} + \frac{p_{2B} - p_{2A}}{2\alpha}], \\
\text{s.t.} \quad & U(p_{2B}, d_{2B}) \geq U(p_{1B}, d_{1B}), \\
& U(p_{1B}, p_{2j}, d_{1B}, d_{2j}) \geq 0, j \in \{B, A\}.
\end{aligned}$$

From a pure mathematical point of view, solving these profit optimization problems yields the two firms' equilibrium levels of prices defined by the following equations.

$$p_{1B} - 2p_{1A} + \alpha + c_0 = 0, \tag{6.5.8}$$

$$p_{2A} - 2p_{2B} + \alpha + c = 0, \tag{6.5.9}$$

$$6\alpha\beta(\alpha + c - p_{2B}) = (p_{1A} - c_0)^2, \tag{6.5.10}$$

$$6\alpha(\alpha + c_0 - p_{1A}) = \beta(p_{2B} - c)^2. \tag{6.5.11}$$

When $\beta = 0$, these equations yield the two firms' equilibrium levels of prices and profits as follows:

$$p_{1A}^{NT} = c_0, p_{2A}^{NT} = \alpha + 2c_0 - c; \tag{6.5.12}$$

$$p_{1B}^{TN} = c_0 - \alpha, p_{2B}^{TN} = \alpha + c_0; \tag{6.5.13}$$

$$\pi_A^{NT} = 0, \pi_B^{TN} = -\alpha. \tag{6.5.14}$$

However, when $\beta = 1$, the resulted equilibrium levels of the two firms' prices are reduced to

$$p_{1A} + p_{2B} = 6\alpha + c_0 + c, \tag{6.5.15}$$

$$p_{1B} + p_{2A} = 10\alpha + c_0 + c, \tag{6.5.16}$$

$$(p_{1B}^{TN} - c_0) + 2(p_{2B}^{TN} - c) = 11\alpha, \tag{6.5.17}$$

$$2(p_{1A}^{NT} - c_0) + (p_{2A}^{NT} - c) = 11\alpha. \tag{6.5.18}$$

But, using the equation (6.5.15) to solve for p_{1A} in equation (6.5.10) we have no solution. Therefore in this case no equilibrium exists.

From an economic point of view, however, the restriction of $\beta \in (0, 1]$ must be assumed. Then, using continuity property we can easily generalize these results to conclude that the equilibrium levels of prices and profits approach those given in (6.5.12) - (6.5.14) when β goes to zero while no equilibrium exists when β goes to 1.

Moreover, by the continuity property the direct competitors case holds as long as $(1+\beta)r - p_{1A}^{NT} - \beta p_{2A}^{NT} - \frac{\alpha}{2} > 0$, $(1+\beta)r - p_{1B}^{TN} - \beta p_{2B}^{TN} - \frac{\alpha}{2} > 0$, and $(1+\beta)r - p_{1B}^{TN} - \beta p_{2A}^{NT} - \frac{\alpha}{2} > 0$. These conditions are satisfied when the customer's reservation price is sufficiently high and β goes to zero. This means that $r > \frac{\alpha}{2} + c_0$. Moreover, when β goes to zero, the customer surplus and the social welfare are given by

$$\begin{aligned} CS^{NT} &= \textstyle\int_0^{\frac{1}{2}} \int_0^{\frac{1}{2}} [(1+\beta)r - p_{1A}^{NT} - \beta p_{2A}^{NT} - \alpha(g_{1A} + \beta g_{2A})] dg_{2A} dg_{1A} \\ &\quad + \textstyle\int_0^{\frac{1}{2}} \int_0^{\frac{1}{2}} [(1+\beta)r - p_{1B}^{TN} - \beta p_{2A}^{NT} - \alpha(g_{1B} + \beta g_{2A})] dg_{2A} dg_{1B} \\ &\quad + \textstyle\int_0^{\frac{1}{2}} \int_0^{\frac{1}{2}} [(1+\beta)r - p_{1B}^{TN} - \beta p_{2B}^{TN} - \alpha(g_{1B} + \beta g_{2B})] dg_{2B} dg_{1B} \\ &= \tfrac{3(r-c_0)}{4} + \tfrac{5\alpha}{16} \end{aligned} \tag{6.5.19}$$

and

$$SS^{NT} = \tfrac{3(r-c_0)}{4} - \tfrac{11\alpha}{16}. \tag{6.5.20}$$

Summarizing, we have the following proposition.

Proposition 6.5.1 *Given unilateral tying of the aftermarkets, the two firms are (i) local monopolists and the equilibrium configurations are given in (6.5.1)-(6.5.7) if* $r < \frac{\alpha+(c_0+\beta c)}{1+\beta)}$; *(ii) direct competitors in an entirely covered market and the equilibrium configurations approach those given in (6.5.12)-(6.5.14) and* (6.5.19) – (6.5.20) *if* $r > \frac{\alpha}{2} + c_0$ *and* β *goes to* 0; *and (iii) no equilibrium exists if* r *is sufficiently high and* β *is sufficiently close to* 1.

□

6.6 Equilibria of the game

Having discussed the alternative choices of the firms in tying their respective aftermarkets, we are now in a position to turn to the preceding stage of the two-stage game for its symmetric subgame perfect equilibria. At the first stage, the two firms solve the reduced normal-form game as given in **Figure** 6.5. We may distinguish subsequently between the local monopoly case and the direct competition case in our discussion of the equilibria of the game.

	Tying	Not tying
Tying	π^{TT}, π^{TT}	π^{TN}, π^{NT}
Not tying	π^{NT}, π^{TN}	π^{NN}, π^{NN}

Figure 6.5 Reduced normal-form game.

Local monopolists. In this case, direct comparison between the firms' profits as given in equations (6.3.4), (6.4.5) and (6.5.5) shows that $\pi^{TT} < \pi^{NT} = \pi^{TN} < \pi^{NN}$. This leads the two firms not to tie their aftermarkets but to compete on it.

A local monopoly is sustained when the consumer's reservation price is sufficiently low, that is, when $r < min\{\frac{3\alpha+2(c_0+\beta c)}{2(1+\beta)}, \frac{5\alpha+6(c_0+\beta c)}{6(1+\beta)}, \frac{\alpha+(c_0+\beta c)}{1+\beta}\} = \frac{5\alpha+6(c_0+\beta c)}{6(1+\beta)}$. Summarizing, we have the following proposition.

Proposition 6.6.1 *If the consumer's reservation price is sufficiently low, $r < \frac{5\alpha+6(c_0+\beta c)}{6(1+\beta)}$, then both firms are local monopolists and choose not to tie their aftermarkets but to compete on it.*

□

This is a quite intuitive result, which can be interpreted as follows. When the consumer's reservation price is sufficiently low, the market is not covered and both firms are local monopolists. In this case, opening aftermarkets to competition increases the variety of the products supplied and thus meets the diversity of the consumers' tastes. As a result, more consumers will stay in the markets. This not only gives the capacity for both firms to increase the prices of their "pseudo-system" goods (it is straightforward to check that $p_{1A}^{NN} + \beta p_{2A}^{NN} > p_{1A}^{TT} + \beta p_{2A}^{TT}$), but increases also their respective market shares. Thus, the profits of both firms are increased through competition on the aftermarkets. This might not be the case, however, when the consumer's reservation price is sufficiently high and the markets are covered, as shown in the following.

Direct competitors. In this case, both firms get profits

$$\pi^{TT} = \pi_A^{TT} = \frac{\alpha(1+\beta)^3}{16\beta} = \frac{\alpha(1+\beta)}{2}\frac{(1+\beta)^2}{8\beta},$$

if they tie their respective aftermarkets, and

$$\pi^{NN} = \pi_A^{NN} = \frac{\alpha(1+\beta)}{2}$$

if they choose not to tie their respective aftermarkets but compete on it.

To derive the subgame perfect equilibrium in this case, we need to take the unilateral tying case into consideration, for which we may distinguish between the two cases that β goes to zero and β goes to 1. In the former case, direct comparison shows that $\pi^{TT} > \pi^{NN}$. Moreover, it is easy to show that both $\pi^{NN} > \pi^{TN}$ and $\pi^{NN} > \pi^{NT}$ hold because π^{TN} goes to $-\alpha$ and π^{NT} goes to 0 when β goes to zero. Thus, two subgame perfect equilibria arise, and these two firms either both tie their respective aftermarkets or compete on their aftermarkets. Since profits are higher if both firms tie their aftermarkets, both firms' tying of their aftermarkets may survive as a unique equilibrium if they could coordinate on tying.

In the second case, we have already shown that no equilibrium price exists as β goes to 1, and thus no equilibrium exists for this game. We may prove as follows, however, that as β goes to 1, one firm may prefer to tie its aftermarket whenever the other does not. First, it is easy to check that π^{TT} goes to $\frac{1}{2}\pi^{NN}$ as β goes to 1. Second, we may prove that $\pi^{NT} \geq \pi^{NN}$ and $\pi^{TN} \geq \pi^{NN}$ if any equilibrium exists as β goes to 1. In fact, let $\beta = 1$, then $\pi^{NT} = \pi^{NT}(p_{1A}^{NT}, p_{2A}^{NT}, p_{1B}^{TN}, p_{2B}^{TN}) \geq \pi^{NT}(p_{1B}^{TN}, p_{2B}^{TN}, p_{1B}^{TN}, p_{2B}^{TN}) = \frac{1}{4}[(p_{1B}^{TN} - c_0) + 2(p_{2B}^{TN} - c)]$. But the equation (6.5.17) shows that $p_{1B}^{TN} - c_0 + 2(p_{2B}^{TN} - c) = 11\alpha$ holds. Therefore, we have that $\pi^{NT} \geq \frac{11\alpha}{4}$. Similarly, we can show that $\pi^{TN} \geq \frac{11\alpha}{4}$. We know, however, that $\pi^{NN} = \alpha$ if $\beta = 1$, so we have that both $\pi^{NT} > \pi^{NN}$ and $\pi^{TN} > \pi^{NN}$ hold.

Finally, in the case that β goes to 0, the direct competitors case holds as long as the reservation price is sufficiently high, that is, $r > \{\frac{\alpha(3+\beta)+2(c_0+\beta c)}{2(1+\beta)}, \frac{3\alpha(1+\beta)+2(c_0+\beta c)}{2(1+\beta)}, \frac{\alpha}{2}+c_0\} = \frac{3\alpha(1+\beta)+2(c_0+\beta c)}{2(1+\beta)}$.

Thus, in summary we have the following proposition.

Proposition 6.6.2 *Suppose that the consumer's reservation price is sufficiently high, i.e.* $r > \frac{3\alpha(1+\beta)+2(c_0+\beta c)}{2(1+\beta)}$ *holds. Then, the two firms either tie or compete on their aftermarkets if they discount their aftermarket profits sufficiently; and tying is particularly chosen if both firms coordinate on it. Otherwise, no equilibrium exists.*

□

This result should be also intuitive and can be interpreted as follows. When the consumer's reservation price is sufficiently high, the potential markets are completely covered, and the value of the aftermarket becomes important. If the value of the aftermarket is sufficiently unimportant, unilateral tying will not only lead the two firms to loose their market shares significantly (because consumers' diversity of tastes can not be fullfiled and some consumers will then stay out of the markets), but also make their primary markets less valuable than competition on aftermarkets, and thus hurts both firms most severely. As a result, these two firms may either agree on tying their respective aftermarkets or competition on their aftermarkets. Furthermore, tying of the aftermarkets may take place if the two firms could coordinate on it because this will make their respective primary markets more valuable and thus increases their profits significantly. If their aftermarkets become very valuable, however, no agreement can be reached between the two firms. This is because either firm prefers tying whenever the other does not and vice versa. They can not, however, reach an agreement on the prices they prefer to charge.

6.7 Welfare

Having derived the firms' equilibrium choices of tying, we are now able to analyse the welfare implications of these choices explicitly. This analysis may answer the social antitrust concerns discussed in our introduction section. The analysis can be performed by distinguishing again between the local monopoly case and the direct competition case.

Local monopolists. The discussion shows that two firms will behave as local monopolists if the customer's reservation price is sufficiently low. In this case, our analysis shows that the following holds:

$$SS^{TT} = \frac{20[(1+\beta)r-(c_0+\beta c)]^3}{81\beta\alpha^2},$$

$$\begin{aligned} SS^{NT} &= \tfrac{583}{2592\alpha^2\beta}[(1+\beta)r - (c_0+\beta c)]^3, \\ SS^{NN} &= \tfrac{126}{125\alpha^2\beta}[(1+\beta)r - (c_0+\beta c)]^3. \end{aligned}$$

Direct comparison shows that $SS^{NN} > SS^{TT} > SS^{NT}$. Since the two firms will compete on their aftermarkets when the consumer's reservation price is sufficiently low, the social welfare is then maximized.

Direct competitors. The discussion shows also that the two firms will act as direct competitors if the customer's reservation price is sufficiently high. Moreover, the social welfare holds as follows:

$$SS^{TT} = (1+\beta)r - (c_0+\beta c) + \frac{\alpha(1+\beta)}{4}\frac{3\beta^2 - 14\beta + 3}{6\beta},$$
$$SS^{NN} = (1+\beta)r - (c_0+\beta c) - \frac{\alpha(1+\beta)}{4},$$
$$SS^{NT} = \frac{3(r-c_0)}{4} - \frac{11\alpha}{16} \text{ if } r > \tfrac{\alpha}{2} + c_0 \text{ and } \beta = 0.$$

It is straightforward that $SS^{TT} > SS^{NN} > SS^{NT}$ holds. Using continunity we can easily generalize this result to conclude that $SS^{TT} > SS^{NN} > SS^{NT}$ for β close to zero. Thus, social welfare is maximized if the two firms could coordinate on tying. To summarise, we have the following proposition.

Proposition 6.7.1 *The social preference and the firms' choices of tying are consistent if the consumer's reservation price is sufficiently low, or if it is sufficiently high but the aftermarkets are sufficiently unimportant and the two firms could coordinate on tying.*

□

This proposition is quite direct also in the case that the consumer's reservation price is sufficiently low. In this case, competition on aftermarkets, on the one hand, increases the variety of the products supplied and thus meets the diversity of consumers' tastes and benefits the consumers. On the other hand, it also gives the firms more potential to increase both their prices and market shares, and thus their profits because of consumers' increased willingness to pay. Therefore, it benefits also the firms. As a result, the social welfare is increased by competition on the aftermarkets. In the case that the consumer's reservation price is sufficiently high, however, the two firms can only reach an agreement if the aftermarkets are sufficiently unimportant. In this case, although the aftermarkets are not so valuable, tying of the aftermarkets makes the primary markets more valuable and thus benefits the firms. Since the market is covered, and consumer surplus does not change significantly relative to the benefits which the two firms gain from tying of their respective aftermarkets, an agreement on tying reached between these two firms will then maximize the social welfare if the two firms could coordinate on it.

6.8 Conclusion

The vertical restraint of tying by durable-goods producers involves antitrust concerns and stimulates economists to find theoretical foundations. Up to date, however, existing results on this issue are quite controversial. While firms are shown to have incentives to exercise monopoly power in their proprietary aftermarkets (see Borenstein, MacKie-Mason and Netz (1996), for example), monopoly power in a monopolized aftermarkets rarely exists for a durable-goods producer, as argued in Shapiro and Teece (1994). Moreover, price discrimination, maintaining equipment market control and positions are argued to be among the alternative reasons of durable-goods producers' tying. Finally, welfare implications of the vertical restraint of tying remain ambiguous.

Our analysis may add new insights to these controversies. We have extended a stylized model of Matutes and Regibeau (1988), where two durable-goods producers decide simultaneously on whether to use the vertical restraint of tying to protect their proprietary aftermarkets from competition. The symmetric subgame perfect equilibria of a two-stage game are demonstrated.

We show that when the consumer's reservation price is sufficiently low, both firms prefer competition on, rather than tying of, their aftermarkets. When the consumer's reservation price becomes sufficiently high, however, both firms may prefer either competition on or tying of their aftermarkets provided that they assign their aftermarkets a sufficiently low value. Tying of their aftermarkets is particularly chosen if both firms could coordinate on it. Moreover, while welfare remains ambiguous in the existing literature on tying of the aftermarkets, our analysis of welfare implications is clear-cut. That is, the social preference is consistent with the firms' choices of tying if the customer's reservation price is sufficiently low, or if the consumer's reservation price is sufficiently high but the aftermarkets are sufficiently unimportant and both firms could coordinate on tying.

Thus far, we have interpreted δ simply as a discount factor. This discount factor, however, could also embody changes in the expected size of a market. If the market is declining in size, for example, the future market share is then less valuable, implying a higher δ but a lower β. Thus, the social welfare is maximized if both firms tie their aftermarkets to their equipment markets provided that the consumer's reservation price is sufficiently high, and therefore leads to the consistence between the firms' choices of tying and the social preference (or welfare).

Briefly speaking, we have confirmed, first of all, in an imperfectly competitive market the Blair and Herndon's (1996) findings in the competitive and monopoly markets, that is, the vertical restraints of tying have little to do with the usual antitrust concerns. Second, we have improved Borenstein, MacKie-Mason and Netz's (1996) result by showing that the durable-goods producers not only have incentives to exercise market power in a proprietary aftermarkets protected by vertical restraints of tying, but may also choose to coordinate on tying to protect their aftermarkets provided that both the consumer's reservation price and the discount factor are sufficiently high. Finally, there will exist consistency between the firms' choices of tying and the social preference if the consumer's reservation price is sufficiently high and the two firms could coordinate on tying of the aftermarkets which is sufficiently unimportant to them.

References

BLAIR, R.D. AND J.B., HERNDON, 1996, "Restraints of Trade by Durable Good Producers", *Review of Industrial Organization*, 11, 339-353.

BOOM, A., 1995, "A Note on the Desirability of Compatibility with Product Selection", Discussion paper DP-95-44, Humboldt University Berlin.

BORENSTEIN, S., J.K., MACKIE-MASON AND S.J., NETZ, 1996, "Exercising Market Power in Proprietary Aftermarket", Manuscript, University of California Energy Institute, University of Michigan and Purdue University.

KATZ, M. AND C., SHAPIRO, 1985, "Network Externalities, Competition, and Compatibility", *American Economic Review*, 75, 424-40.

MATUTES, C. AND P., REGIBEAU, 1992, "Compatibility and Bundling of Complementary Goods in a Duopoly", *The Journal of Industrial Economics*, XL, 37-54.

——, 1988, "Mix-and-Math: Product Compatibility without Network Externalities", *RAND Journal of Economics*, 19, 221-234.

ECONOMIDES, N., 1989, "Desirability of Compatibility in the Absence of Network Externalities", *The American Economic Review*, 79, 1165-1181.

DE BIJL, P.W.J., 1996, "Aftermarket: The Monopoly Case", *Essays in Industrial Organization and Management Strategy*, Ph.D Thesis, ISNB 90 5668 012 9, Tilburg University, Tilburg.

KLEMPERER, P., 1995, "Competition when Consumers have Switching Costs: An Overview with Applications to Industrial Organization, Macroeconomics, and International Trade", *Review of Economic Studies*, 62, 515-539.

——, 1987b, "The Competiveness of markets with Switching Cost", *The Rand Journal of Economics*, 18, 138-150.

SCHERER, F.M. AND D., ROSS, 1990, *Industrial Market Structure and Economic Performance*, Houghton Mifflin Company Boston, Third Edition, 564-565.

SHAPIRO, C., AND D.J., TEECE, 1994, "Systems Competition and Aftermarkets: An Economic Analysis of *Kodak*", *Antitrust Bulletin*, 39, 135-162.

VOORTMAN, J.J., 1993, "Curbing Aftermarket Monopolization", *Antitrust Bulletin*, 38, 221-291.

VON WEIZSÄCKER, C., 1984, "The Costs of Substitution", *Econometrica*, 52, 1085-1116.

WILLIAMSON, O., 1985, *The Economic Institutions of Capitalism*, New York, Free Press.

Samenvatting

Dit proefschrift analyseert de oorzaken van het in toenemende mate heterogeen worden van producten in een moderne markteconomie, zowel in fysieke verschijning als in kwaliteit. Als oorzaken kunnen worden genoemd: mededinging van derde goederen, evenals niet-uniforme maar geconcentreerde dichtheden van consumenten, en competitie en coöperatie. De toepassingen zijn tweeërlei. Een politiek kan worden bepaald ten aanzien van de verbinding door de duurzame-goederenproducenten van de primaire markten met hun na-markten op grond van de hierdoor gegenereerde welvaartseffecten. Daarnaast kan een internationaal handelsbeleid worden bepaald inzake de standaardisering van bepaalde goederen door de overheid en door bedrijven. De analyse wordt gericht op de wijze waarop een binnenlandse duurzame-goederenproducent, die een gevestigde kwaliteitsvolger is, onder internationale competitie en overheidsbescherming met een buitenlandse duurzame goederenproducent tot overeenstemming zal komen op standaardisering. De belangrijkste conclusies luiden als volgt.

Ten eerste. Beschouw een verticaal gedifferentieerd duopolie à la Shaked en Sutton (1982), met een nauw kwaliteitsspectrum voor de beide bedrijven. Deze worden dan in een beperkte productruimte gevoegd, waarin de competitie zó sterk kan worden dat het effect van de externe goederen strikt gedomineerd wordt en beide bedrijven altijd zullen trachten hun producten maximaal te differentiëren in het gegeven spectrum. Aan de andere kant, wanneer het toegestane kwaliteitsspectrum groot is, zullen de beide bedrijven voldoende ruimte hebben om kwaliteitskeuzen te maken. Competitie zal in dit geval matig zijn en het effect van externe goederen wordt groter. Bij afwezigheid van kostenverschillen is het standaardresultaat dat de lage-kwaliteitsproducent (bedrijf 1) meer productdifferentiatie wil omdat dit de prijsmededinging vermindert en de winsten verhoogt (Tirole, 1988). Wanneer het effect van externe goederen toeneemt, zal bedrijf 1 meer competitie ervaren. Dit effect van de externe goederen is bovendien groter voor bedrijf 1, dan voor de hoge-kwaliteitsproducent (bedrijf 2). De conclusie is dus dat de concurrentie die bedrijf 1 ervaart van bedrijf 2 stijgt naarmate de kwaliteit van externe goederen groter wordt. Bedrijf 1 is dan gebaad bij meer productdif- ferentiatie van bedrijf 2. Ondanks de stijging van de mate van productdifferentiatie zullen de evenwichtsprijzen en -winsten van beide bedrijven afnemen ten gevolge van de toegenomen concurrentie.

Stel vervolgens dat in een soortgelijk verticaal gedifferentieerd duopolie, de kwaliteit van de externe goederen op nul wordt gesteld en beide bedrijven twee andere strategische variabelen ter beschikking hebben: kwaliteit en prijs. Er kunnen zich drie gevallen voordoen: (a) samenwerking inzake beide variabelen, (b) mededinging op kwaliteit en samenwerking op prijsgebied, (c) mededinging op beide variabelen. De analyse toont dat beide bedrijven zullen samenwerken voor wat betreft kwaliteit, alsook bij prijzen, en dat zij hun producten maximaal zullen differentiëren.

Ten derde. Beschouw twee bedrijven met zowel horizontale als verticale productdifferentiatie, analoog aan binnen- en buitenlocatiespelen in locatietheorie. Een geconcentreerde consumentendichtheid veroorzaakt een centripetale marktkracht in het binnenlocatiespel en vergroot de asymmetrie tussen de bedrijven in het buitenlocatiespel. Het gevolg is dat de bedrijven in de binnenmarkt naar elkaar trekken en hun productdifferentiatie in het binnenlocatiespel doen afnemen, terwijl zij van elkaar wegtrekken in de buitenmarkt en hun productdifferentiatie in het binnenlocatiespel verhogen.

Ten vierde. Beschouw bedrijven die systeemgoederen produceren. Een systeemgoed bestaat uit verschillende componenten. Elke component afzonderlijk genomen is nutteloos. Een binnenlands bedrijf produceert systeemgoederen, maar ervaart competitie van een buitenlands bedrijf dat een hogere kwaliteit produceert en beschermd wordt door handelspolitiek, zoals tarieven. De vraag rijst of beide bedrijven het met elkaar eens kunnen worden over standaardisering van hun componenten, gegeven de overheidsbescherming. We laten zien dat handelsliberalisering samenhangt met standaardisering van de componenten van systeemgoe- deren, terwijl protectie kan leiden tot niet-standaardisering als de parameters van de consumentensmaak onafhankelijk zijn. Wanneer echter de parameters van de consumenten- smaak identiek zijn, is de standaardiseringskeuze van de bedrijven onafhankelijk van de handelspolitiek van de overheid. Noch de welvaart, noch het optimale tarief kunnen worden gewijzigd door een eventueel precommitment van de overheid tot een bepaald tarief; de overheid zal altijd de standaardisering ondersteunen.

Ten vijfde, beschouw een bedrijfstak waarin duurzame goederen met na-markten geprodu- ceerd worden. De producenten zullen dan hun na-marktprijzen als strategische variabelen gebruiken om hun winsten te maximaliseren. Dit kan leiden tot aanklachten terzake kartelvorming. Echter, in geval van een duopolie toont de analyse dat de duurzame- goederenproducenten aan mededinging op de na-markten de voorkeur geven boven bescherming van de na-markten door middel van prijskoppeling, indien de reserveringsprijs van de consument voldoende laag is. Maar als deze prijs voldoende hoog is en als de na- marktwinst voldoende verdisconteerd is, dan zijn beide strategieën, prijskoppeling of mededinging, voor de producenten aantrekkelijk. Prijskoppeling wordt in dit geval wel geprefereerd als beide bedrijven dit kunnen coördineren. Maar deze afspraken zijn niet mogelijk als de na-markt hoog genoeg gewaardeerd wordt. Tenslotte blijkt het sociale optimum consistent te zijn met een keuze van prijskoppeling door de bedrijven.

Center for Economic Research, Tilburg University, The Netherlands
Dissertation Series

No.	Author	Title
1	P.J.J. Herings	Static and Dynamic Aspects of General Disequilibrium Theory; ISBN 90 5668 001 3
2*	Erwin van der Krabben	Urban Dynamics: A Real Estate Perspective - An institutional analysis of the production of the built environment; ISBN 90 5170 390 2
3	Arjan Lejour	Integrating or Desintegrating Welfare States? - a qualitative study to the consequences of economic integration on social insurance; ISBN 90 5668 003 x
4	Bas J.M. Werker	Statistical Methods in Financial Econometrics; ISBN 90 5668 002 1
5	Rudy Douven	Policy Coordination and Convergence in the EU; ISBN 90 5668 004 8
6	Arie J.T.M. Weeren	Coordination in Hierarchical Control; ISBN 90 5668 006 4
7	Herbert Hamers	Sequencing and Delivery Situations: a Game Theoretic Approach; ISBN 90 5668 005 6
8	Annemarie ter Veer	Strategic Decision Making in Politics; ISBN 90 5668 007 2
9	Zaifu Yang	Simplicial Fixed Point Algorithms and Applications; ISBN 90 5668 008 0
10	William Verkooijen	Neural Networks in Economic Modelling - An Empirical Study; ISBN 90 5668 010 2
11	Henny Romijn	Acquisition of Technological Capability in Small Firms in Developing Countries; ISBN 90 5668 009 9
12	W.B. van den Hout	The Power-Series Algorithm - A Numerical Approach to Markov Processes; ISBN 90 5668 011 0
13	Paul W.J. de Bijl	Essays in Industrial Organization and Management Strategy; ISBN 90 5668 012 9

---

* Copies can be ordered from Thesis Publishers, P.O. Box 14791, 1001 LG Amsterdam, The Netherlands, phone + 31 20 6255429; fax: +31 20 6203395; e-mail: thesis@thesis.aps.nl

No.	Author	Title
14	Martijn van de Ven	Intergenerational Redistribution in Representative Democracies; ISBN 90 5668 013 7
15	Eline van der Heijden	Altruism, Fairness and Public Pensions: An Investigation of Survey and Experimental Data; ISBN 90 5668 014 5
16	H.M. Webers	Competition in Spatial Location Models; ISBN 90 5668 015 3
17	Jan Bouckaert	Essays in Competition with Product Differentiation and Bargaining in Markets; ISBN 90 5668 016 1
18	Zafar Iqbal	Three-Gap Analysis of Structural Adjustment in Pakistan; ISBN 90 5668 017 x
19	Jimmy Miller	A Treatise on Labour: A Matching-Model Analysis of Labour-Market Programmes; ISBN 90 5668 018 8
20	Edwin van Dam	Graphs with Few Eigenvalues - An interplay between combinatorics and algebra; ISBN 90 5668 019 6
21	Henk Oosterhout	Takeover Barriers: the good, the bad, and the ugly; ISBN 90 5668 020 x
22	Jan Lemmen	Financial Integration in the European Union: Measurement and Determination; ISBN 90 5668 021 8
23	Chris van Raalte	Market Formation and Market Selection; ISBN 90 5668 022 6
24	Bas van Aarle	Essays on Monetary and Fiscal Policy Interaction: Applications to EMU and Eastern Europe; ISBN 90 5668 023 4
25	Francis Y. Kumah	Common Stochastic Trends and Policy Shocks in the Open Economy:Empirical Essays in International Finance and Monetary Policy; ISBN 90 5668 024 2
26	Erik Canton	Economic Growth and Business Cycles; ISBN 90 5668 025 0
27	Jeroen Hoppenbrouwers	Conceptual Modeling and the Lexicon; ISBN 90 5668 027 7

No.	Author	Title
28	Paul Smit	Numerical Analysis of Eigenvalue Algorithms Based on Subspace Iterations; ISBN 90 5668 026 9
29	Uri Gneezy	Essays in Behavioral Economics; ISBN 90 5668 028 5
30	Erwin Charlier	Limited Dependent Variable Models for Panel Data; ISBN 90 5668 029 3
31	Rob Euwals	Empirical Studies on Individual Labour Market Behaviour; ISBN 90 5668 030 7
32	Anurag N. Banerjee	The Sensitivity of Estimates, Inferences, and Forecasts of Linear Models; ISBN 90 5668 031 5
33	Frans A. de Roon	Essays on Testing for Spanning and on Modeling Futures Risk Premia; ISBN 90 5668 032 3
34	Xiangzhu Han	Product Differentiation, Collusion, and Standardization; ISBN 90 5668 033 1

XIANGZHU HAN stu University for Bachelor's degree during 1981-85, and operational research and mathematical economics at the Xi'an Jiaotong University for Master's degree during 1985-88, in P.R. China. Between 1988-1993, he served both for the Chinese government on economic policies and for a private Chinese stock assessment company as an independent auditor. He was awarded engineer in 1990. In 1993 he started his Ph.D. research at the Department of Econometrics and the CentER of Tilburg University, in the field of industrial organization, with the emphasis on product differentiation theory and its applications to collusion and standardization.

This thesis analyzes why products become increasingly heterogenous in both their physical and qualitative appearances in the modern market economy. Among the important causes, competition from outside goods, non-uniform but concentrated consumer distributions, and competition and cooperation, are studied for the demonstration of their economic implications. The applications are twofold. First, there are the incentives of durable-goods producers to tie their aftermarkets with their primary markets, and the social consequences of that action. Second, there are the international trade policies of standardization. The analysis focuses on whether a domestic durable-goods producer, being a quality follower and incumbent, will agree on standardizing its products with a foreign durable-goods producer, under international competition and government protection.

ISBN 90-5668-033-1

CentER Dissertation